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(NASA-CR-117556) LTA-9 FEASIBILITY STUDY REPORT (Grumman Aircraft Engineering Corp.) 177 p

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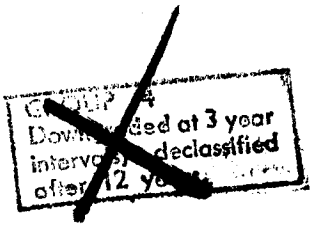

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Changed by L. Shirley Date 12/3/72
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LTA-9 FEASIBILITY STUDY REPORT

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CONTRACT NO. NAS 9-1100

Line Item 18

Primary No. 018

Type Document 2

Ref. Paragraph No. 5.1

Grumman Aircraft Engineering Corporation
Bethpage, Long Island, New York

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Grumman LEM

1. INTRODUCTION

1.1 BACKGROUND

This report presents the results of a two-month engineering study undertaken to evaluate the feasibility of developing an atmospheric free-flight version of the Lunar Excursion Module. The study has been carried out under item 3 (e) of Enclosure 2 to NASA, MSC letter of December 19, 1962, W. F. Rector III. The primary requirement stipulated was to "conduct conceptual design of free flight vehicles for terminal approach, hover, and landing tests."

The task has been divided into two concurrent study efforts: one concerned with modification of the LEM vehicle to meet the foregoing requirements; and the second aimed at formulating concepts for alternate means of providing adequate simulation of LEM characteristics. This latter study encompasses fixed base simulators and free flight vehicles which do not necessarily resemble LEM physically.

1.2 SCOPE

This study has explored possible approaches to modifying the existing LEM configuration to provide an atmospheric free-flight vehicle, designated LTA-9, which is suitable for astronaut training and system checkout during the terminal descent phase of the lunar landing. The designs considered during the study have been based upon retaining all LEM equipment, structure, propulsion, and control elements pertinent to the landing maneuver.

The completion deadline scheduled for this study precedes the date set for the LEM configuration "freeze." Consequently, the LEM Proposal configuration has beeen used as a model for LTA-9 design studies involving aerodynamic characteristics, structural modification , and vehicle weight and balance. Implicit in this approach is the assumption that the generation of a feasible design based upon modification of the proposal configuration will be equally feasible when applied to the final configuration. At this stage of the LEM vehicle design study it appears that the various approaches under consideration are sufficiently similar to the proposal configuration to render the assumption valid.

The scope of the study has included generation of the preliminary program schedule, test plan, and budgetary costs associated with development of the LTA-9 vehicle. Field operation procedures and support requirements have been outlined, and a preliminary evaluation of vehicle usage and capability as compared to alternate training methods has been formulated.

A definitive comparison of LTA-9 over-all capability with that of alternative free flight designs as well as fixed base simulators is contingent upon the results of the concurrent study described in section 1.1 and is consequently not available for the present report. At the conclusion of the concurrent study a final evaluation will be completed and the results presented to NASA.

1.3 STUDY OBJECTIVES

The Grumman study objective has been to carry out conceptual design of the LTA-9 atmospheric free-flight vehicle in sufficient detail to permit determination of feasibility from the standpoints of:

* Simulation of Lunar Environment; duplication of lunar attitude-acceleration coupling and cancellation of aerodynamic effects.
* Vehicle Handling Qualities; ability to match LEM response characteristics during the landing maneuver.
* Vehicle Capability; payload, performance, flight duration.
* Astronaut Safety; propulsion margin, crew escape provisions, vehicle recovery methods.
* Vehicle Utilization; a preliminary evaluation of vehicle capability for training and equipment refinement.
* Development Schedule; availability for operational training, compatibility with LEM schedule.
* Development Cost; design, procurement, fabrication, and test.

It was not the purpose of this study to concentrate on the optimization of one particular solution to the problem. Instead, our goal has been to explore a number of possible configurations and select the more promising approaches for detailed conceptual design and comparison in the light of the factors listed above. The primary technical effort has been directed toward establishing realistic design criteria, identifying the problem areas and constraints associated with meeting these criteria, and carrying design studies to the point where solutions appeared to be within the state-of-the art. Also investigated was the potential system simplification which can be effected if design criteria are relaxed.

1.4 STUDY APPROACH

The first step in the LTA-9 study has been the definition of vehicle requirements in the areas of trajectory envelopes, payload capability, simulation of the lunar environment, and matching of LEM handling characteristics. These requirements are discussed in Section 3.0 of the report.

Next, the basic data required for initiation of vehicle design studies were acquired. Tasks in this category were:

* Calculations of weight, c.g. and inertia of LEM after removal of equipment and expendables not required for the terminal descent maneuver. (Section 4.1)
* Wind tunnel testing of a 1/8-scale LEM model to determine aerodynamic forces and moments (Section 4.2)
* Analysis of the modifications required and resulting performance for atmospheric operation of LEM descent engine and RCS system (Section 4.3)
* Availability check on LEM hardware to be used in LTA-9 development.

One of the major study efforts was devoted to determination and comparison of possible methods of simulating the lunar gravitational environment and cancelling aerodynamic forces and moments. The equipment fulfilling this function has been identified as the Earth Environment Compensation (EEC) system. Work in this area included:

* Survey and selection of "levitation" engines to balance 5/6ths of the earth's gravitational force plus lift and drag components.
* Determination of applicable thrust vectoring methods.
* Investigation of trim systems to handle aerodynamic moments.
* Preliminary design of an automatic control system to drive the above components and investigation of its stability and response time.

A description of this work is presented in Section 5.

A configuration study was carried out concurrently with the EEC investigation. A number of possible "levitation" engine installations on LTA-9 were investigated and the more promising selected for detailed study. The resulting conceptual designs are described in Section 6 and the reasons for selection of the "winner" are advanced.

A preliminary LTA-9 Development Plan, described in Section 7, was evolved based on design, fabrication, and development of the selected conceptual design. As a follow-on to the development program, operational utilization of the vehicle was investigated. This work, described in Section 8.0, included: Formulation of a preliminary training mission description; definition of field support requirements; and a preliminary investigation of crew safety and vehicle recovery provisions.

The report concludes with a description of LTA-9 task capability in the areas of advanced astronaut training and functional testing for the terminal descent phase of the lunar mission.

2. SUMMARY

Our primary feasibility study conclusions are that:

* Development of a modified LEM for atmospheric free flight is technically feasible.

* LTA-9's delivery date to NASA will permit a minimum of a one year period for astronaut operational training prior to the first manned lunar landing.

* LTA-9 affords the opportunity to upgrade and refine LEM operational equipment and landing techniques in a flight environment. This potential starts in mid-1965 with the commencement of flight testing and continues through the astronaut operational training period - an overall time span of $2\frac{1}{2}$ years.

2.1 SIMULATION OF LUNAR ENVIRONMENT

The LTA-9 configuration is a basic LEM to which has been added a model adaptive control system plus auxiliary lift and trim provisions to insure that the following conditions, required for lunar environment simulation, are met:

* Rocket thrust-to-vehicle mass ratio: equivalent to lunar LEM
* RCS torque-to-vehicle inertia ratio: equivalent to lunar LEM
* Auxiliary lift to balance difference between lunar and earth gravity
* Cancellation of aerodynamic effects

These requirements are satisfied by the Earth Environment Compensation (EEC) System described in section 5 of this report. Elements of the system are:

a) A jet-engined levitation system with 2-axis thrust vectoring which provides longitudinal, lateral, and vertical thrust components as required to balance drag, lift, and 5/6 of the earth's gravitational force.

b) A bleed-air reaction control system to balance out pitch, yaw, and rolling moments induced by aerodynamic forces, and c.g. shift, and to supplement the LEM RCS as required to attain desired rotational acceleration response.

c) An automatic control system which computes the lunar acceleration that would result for a given vehicle attitude, weight, and control input; measures the actual acceleration; and uses the difference signal to command appropriate elements of the EEC to null out acceleration errors.

In addition to balancing gravitational and aerodynamic effects, the EEC can compensate for mass and inertia mismatches between LEM and LTA-9. The overall approach is similar in concept to that planned by Bell Aero-systems for use in their Lunar Landing Research Vehicle (LLRV) which is currently being developed under contract to NASA.

2. SUMMARY (Cont.)

A preliminary linear analysis of the EEC system indicates that the system is stable and will enable LTA-9 to match the LEM handling characteristics expected during lunar terminal descent. Furthermore, the EEC system can be implemented with state-of-the-art technology and hardware.

2.2 LTA-9 TRAJECTORY REQUIREMENTS

LTA-9 minimum performance requirements are based upon a model trajectory which was selected to represent the most severe approach likely to be encountered in an actual lunar landing. This trajectory, described in section 3.0, calls for a maximum velocity of 73.7 feet/sec. at an angle of attack of 61 degrees, a maximum pitch attitude of 32°, and a maximum pitch rate of 21 1/2 degrees per second. Adequate pitch trim power (3600 ft. pounds) is available from the bleed-air RCS system to handle the maximum aerodynamic moment occurring during the trajectory (1200 ft. pounds). Pitch trim power is saturated by aerodynamic moments at about 87 feet per second at zero angle of attack.

Nominal LTA-9 mission profile consists of: take-off and climb to 1000 feet on jet engine system (1 minute), transition to initial landing conditions and rocket engine light-off (1-1/2 minutes), and terminal descent to touch down (2-1/2 minutes max.) An additional minute of jet engine operation is provided for warmup and reserve.

Take-off is from the WSMR terrain altitude of 4000 feet. Maximum altitude capability of 3900 feet above WSMR terrain is attained by a 2-1/2 minute climb followed by an immediate descent. For this mission profile, average landing trajectory sink rate must exceed 26 feet per second.

2.3 LEM MODIFICATIONS FOR LTA-9

Modifications to the basic LEM vehicle consist of:

* Removal of the ascent engine and tankage plus additional expendables and components not required for the terminal descent portion of the mission.

* Simplification of the power supply and environmental control systems.

* Replacement of the LEM landing gear with a "work horse" gear suitable for repeated use.

* Modification of the Descent Propulsion & RCS systems for atmospheric operation.

* Addition of the Earth Environment Compensation system elements.

* Installation of zero speed-zero altitude ejection seats for crew safety.

The resulting vehicle, described in section 6.3, uses six General Electric

2. SUMMARY (Cont.)

SJ-132 (modified J-85) jet engines with 2-axis thrust vectoring plus a bleed-air reaction control system to provide the necessary auxiliary lift and cancellation of aerodynamic lift, drag and moment effects. The engines are mounted three per side in a horizontally opposed configuration to cancel the gyroscopic effects which would otherwise occur during angular motion of the vehicle. The thrust vectoring system maintains the thrust parallel to the gravity vector for vehicle excursions of ± 30 degrees in pitch and ± 15 degrees in yaw.

Vehicle gross weight of 10,407 pounds includes 1674 pounds of rocket propellant and 1045 pounds of jet fuel. Weight at touch down is 7723 pounds with 71 pounds of jet fuel in reserve. Balanced-thrust (four engines operating) engine-out capability with rocket engine inoperative and a full rocket propellant load aboard can be attained at a 4000 foot altitude (above S.L.) and "standard day" temperature using an emergency throttle setting of 110% of take-off thrust. Thrust available under "tropical day" conditions is insufficient to meet present maximum-weight thrust required unless all bleed-air is shut off or diverted downward.

2.4 DEVELOPMENT TEST PROGRAM

Anticipated development time for LTA-9 is 3 1/2 years. The program calls for fabrication of two vehicles which are used for structural proof tests, flight test, and for operational training. An 18 month flight test program is scheduled. The first eleven months are devoted to tethered, hover, and free flight tests at Grumman's Peconic River Facility using jet engines and bleed-air RCS only. The final months of testing are conducted at WSMR using both jet engine and descent stage rocket propulsion. Throughout this period direct feedback of test results, applicable to the basic LEM program, will be maintained. Assuming a 1 July '63 go-ahead, two vehicles would be available for operational training by the end of 1966.

2.5 LTA-9 CAPABILITY

LTA-9 capabilities can be summed up as follows:

* Payload capacity: includes all equipment, rocket propulsion and RCS components used during the lunar terminal descent.
* Crew station provisions: controls, displays and visibility are essentially identical to LEM.
* Flight trajectory envelope: predicted LEM extremes of velocity and and attitude occurring below the hover point can be attained with the trim power provided.
* Simulation of the lunar environment and duplication of LEM response characteristics: can be provided using a feasible technical approach for balancing gravitational and aerodynamic force.
* Crew safety provisions: include capability for control with either LEM or bleed-air RCS; jet engine-out flight capability with rocket inoperative; and zero-zero ejection seats.

2. SUMMARY (Cont.)

* Dual training mode: to permit landing practice on jet-engines only or on rocket engine plus auxiliary lift from the jets.

The conceptual LTA-9 design contains an equipment installation, including RCS and descent rocket tankage and plumbing, that will be quite similiar to the LEM. The flight test and flight training phases of LTA-9 operation provide a means for post-flight observation and inspection of LEM hardware. This terminal descent flight experience provides the opportunity to upgrade LEM equipment and thereby complements the currently planned LEM Ground and Space Flight Test Program.

2.6 ADDITIONAL STUDY RESULTS

The more important additional results and considerations arising from the study are briefly summarized below.

* Wind tunnel data on the "proposal" LEM configuration indicates that aerodynamic pitching moment exceeds the bleed-air trim control power of the conceptual design at a velocity of 87 FPS. Therefore LTA-9 - LEM flight simulation does not include the flare portion of the deorbit-descent trajectory.

* The EEC system can be considerably simplified if LTA-9 flight velocity is restricted to 25 FPS. Below this nominal velocity the lunar-earth translational acceleration difference due to aerodynamics is negligible (on the order of .005 g's). The EEC system therefore need only consider gravity differences.

* Replacement of the levitation propulsion concept with an approach that uses a single higher performance LEM-type descent rocket engine simplifies the vehicle at the expense of sacrificing simulation of lunar flight dynamics and decreasing mission flight time.

* LTA-9 is the only LEM-type vehicle in which LEM hardware, including the (modified) descent engine and RCS, is excercised in free flight and returned to earth intact.

* Minimum descent engine thrust chamber design life will be 480 seconds. The operational mission cycle will require additional thrust chambers and engines periodically. This will provide an additional source of engine reliability data and also give the flight crews experience in managing a wider cross-section of production rocket engines.

3. DEFINITION OF VEHICLE REQUIREMENTS

3.1 TERMINAL DESCENT TRAJECTORY ENVELOPE

In order to establish a preliminary design requirement for maximum horizontal velocity, sink rate, and pitch-yaw excursions during terminal descent, representative trajectory data were compiled. This information, shown in Table 3.1, was derived from X-14A flight experience, NASA and Grumman simulator studies, anticipated performance of the Bell LLRV, and the Langley Tethered Lunar Landing Research Facility. Data are presented for a hypothetical "most severe" terminal descent trajectory which has evolved during a concurrent Grumman study on free-flight simulator requirements. In addition the terminal descent parameters of the LEM proposal trajectory are included.

The "most severe" profile is illustrated and discussed in Section 5.0. It represents a profile that is within pilot and LEM limitations, but is sufficiently extreme to represent a possible simulator design goal. Consequently, this trajectory has been used as a model for determining the forces and moments which must be handled by the EEC system. A brief summary of the selected design requirements based on critical elements of the various trajectories is as follows:

Normal Hover Altitude:	1000 feet above terrain
Maximum Resultant Velocity:	80 feet/second
Maximum Pitch Attitude:	± 30 degrees
Maximum Roll Attitude (LEM yaw) :	± 15 degrees
Maximum Yaw Attitude (LEM roll) :	Unlimited
Time to Touchdown:	$2\frac{1}{2}$ minutes
Touchdown Conditions:	
Sink rate:	10 feet/sec.
Hor. velocity:	5 feet/sec.
Attitude:	Veh. X (vert.) axis 5 deg. from vertical

In addition to establishing a terminal descent trajectory model for LTA-9, a preliminary mission profile was established which covers the complete flight from take-off to touchdown. The profile consists of: take-off and vertical climb to an altitude of 1000 feet in one minute on jet engine and bleed-air RCS; a $1\frac{1}{2}$ minute period of level flight for rocket engine light-off and establishment of terminal descent initial conditions; and a descent to touchdown with rocket engine on and the jet system supporting five-sixths of the vehicle's instantaneous weight. Total mission time is 5 minutes. This profile has been used as a model in establishing jet engine take-off thrust requirements and total jet engine fuel weight for the configurations investigated in the design study. WSMR terrain altitude (4000 feet) and "Tropical day" conditions were assumed. The profile is illustrated and further described in Section 8.

3.2 PAYLOAD CAPABILITY

LTA-9 payload requirements are based on the following ground rules:

* Retention of all equipment, controls, and displays used during terminal descent.
* Deletion of equipment and expendables not required for terminal descent.
* Replacement of lunar landing gear with "workhorse" gear.
* Addition of new equipment for:
- Earth Environment Compensation System
- Crew safety
- Possible vehicle recovery provisions.

The weight derivation of the "stripped" LEM is tabulated and described in section 4.1. Weight and balance characteristics of the conceptual designs are presented in section 6.0.

3.3 SIMULATION OF LUNAR ENVIRONMENT

Two elements of the lunar environment which exert a marked influence on vehicle response and which can be simulated in an atmospheric free-flight vehicle are the reduced lunar gravitational force and the absence of aerodynamic effects. In our feasibility study it was considered important to establish the degree of complexity necessary to simulate these conditions as closely as possible. The conceptual designs discussed in this report, consequently, have been designed to meet this requirement.

It is also important to be aware of the simplifications that can be effected if the simulation is degraded to some extent. The complexity of the control system can be greatly reduced if the resultant velocity requirement is lowered to approximately 25 feet per second. As shown by the wind tunnel data presented in section 4.2, the lift, drag and moment values at this velocity are extremely low and relatively insensitive to changes in angle of attack. The translational decelerations induced by lift and drag forces are on the order of .005 g's, well below the limit of flight acceleration sensors and pilot thresholds. The pitching moment is a maximum of 250 to 300 foot pounds. Under these conditions it appears feasible to neglect aerodynamic effects or at most incorporate a bias in the system to balance out the average effect. The resulting simplification in the EEC control system is described in section 5.

Simulation of the attitude-acceleration coupling which will occur on the moon requires application of an auxiliary lift vector equal to 5/6 of the vehicle's instantaneous weight acting through the c.g. in a direction which opposes the local gravity vector. Meeting these requirements requires two-axis vectoring of the auxiliary thrust vector to accommodate vehicle pitch and yaw attitude excursions. The tilt angle to obtain a given lateral acceleration on the earth is roughly 1/6 the tilt required on the moon ($\tan \theta_e = \tan \theta_{m/6}$). If required attitude changes are small during the terminal descent, the possibility of utilizing a single fixed "lift" thrust vector exists. A control scheme for an all-rocket atmospheric free-flight version of LEM which uses this approach is described in section 5. Rocket engine modifications and vehicle performance are also presented in section 5.0. The resulting configuration and weight breakdown are shown in section 6.0, and a preliminary development program for the vehicle is given in section 7.0.

In summary, the primary configurations described in the report have been designed to simulate closely the handling characteristics representative of the lunar environment. The design simplification which results from relaxing these requirements has also been investigated.

3.4 DUPLICATION OF LEM MASS PROPERTIES

Atmospheric operation of the LEM descent engine during the terminal descent requires more than twice the propellant (1674 vs. 828 pounds) used during an equivalent lunar trajectory. Also, approximately 340 pounds of jet fuel is burned during a typical LTA-9 descent to touch down. As a consequence it is not possible to duplicate LEM weight-time history even if weights are initially matched.

In order to match LEM linear and angular acceleration response characteristics, however, a duplication of the LEM weight-time history is not required. It is necessary, however, to match both rocket thrust-to-vehicle mass ratio and RCS torque-to-vehicle inertia ratio. In addition, 5/6 of the vehicle weight must be supported by auxiliary means and aerodynamic effects must be balanced as previously described. Satisfaction of these requirements is implemented by the EEC system as described in Section 5.0 of this report.

The LEM center of gravity location defines the point about which the vehicle will rotate when subjected to pure couples by the RCS. To match LEM motion in response to control inputs, therefore, it is necessary that both c.g. location and travel be duplicated closely in LTA-9. Weight and balance characteristics for several conceptual designs, presented in Section 6. show that a c.g. mismatch is present with respect to the proposal LEM configuration. The results of a preliminary analysis indicate that sufficient design flexibility is available to minimize or eliminate this mismatch.

TABLE 3-1

A COMPARISON OF TERMINAL TRAJECTORY PARAMETERS

	FLIGHT PATH PARAMETERS									TOUCHDOWN CONDITIONS		
	Max. Crew	Displays	Normal Hover Altitude-ft. above terrain	Horiz. Velocity Compartment-fps	Vertical Velocity Compartment-fps	Max. Pitch Attitude-Degrees	Max. Roll Attitude-Deg. (LEM Yaw)	Max. Yaw Attitude-Deg. (LEM Roll)	Time to Touchdown-Seconds	Sink Rate-fps	Horizontal Velocity-fps	Attitude from Vertical-Deg.
VEHICLE												
LEM (Proposal Trajectory)	2	LEM	1000	11.8	12	±45°	±45	±360°	105	10	5	±5°
LTA-9 ("Severe" Trajectory)	2	LEM	1000	35.8	64.4	±30°	±15°	±360°	120	10	5	±5°
Langley Tethered LLRF	2	R&D	155	50	20	±45°	±30°	±270°	180	10	-	±15°
Bell LLRV	1	R&D	1000	30	70*	±60°	±40°	±40°	120	--	-	--
X-14A (NASA TN D-1649)	1	Aircraft Type	1000	55 (avg.)	11 (avg.)	±20**	±10**	±10	91 to 120	3	3	--
STUDIES AND SIMULATORS												
NASA WP 1045 (APPENDIX H)	2	LEM	300	35	10	±45°	±45°	±45°	76.5	3.2	-	--
NASA TN D-1484 (6° Simulator)	2	R&D	1000	--	47	--	--	--	120	4	4	--
GAEC Proposal Period (6° Simulator)	1	R&D	1000	25	10	±15°	±10°	±10°	105	10	5	±5°

* Maximum Capability
** Equivalent lunar angle

4. BASIC DATA

4.1 LEM WEIGHT REVISIONS

Proper investigation of LTA-9 capabilities is dependent upon realistic weight, balance and inertia data. Using the basic LEM proposal weight itemization, a "stripped" LEM configuration was derived. The LTA-9 conceptual configurations were developed around this "stripped" LEM. The derivation of the stripped weight is shown in table 4-1. The code numbers shown are those used in the detailed "LEM Proposal" weight breakdown, and the items listed are those which have been eliminated or modified. All other LEM equipment (Navigation and Guidance, Stabilization and Control components, etc.), have been retained in LTA-9.

The approach was based upon deletion of items not required in the LEM terminal descent phase and addition of equipment that would be common to all atmospheric LTA-9 configurations. The major LEM deletions were four of the six descent propellant tanks, the ascent engine and propellant and the scientific instrumentation. The additions included personnel ejection seats, structural modifications, battery power supply in lieu of the heavier fuel cells, a simpler environmental control subsystem and a modified landing gear. A detailed weight statement listing all the LEM equipment to be installed in LTA-9 is presented in table 4-2.

Items with weights or locations unique to a particular configuration were added to derive the specific configuration gross weight, c.g. and inertia data presented in section 6.

TABLE 4-1

LTA-9 DERIVATION OF STRIPPED WEIGHT

Code	Item Removed/ Added	Gross Weight (LEM)	Less	Plus	Net	Δ Weight
1.0	Structure	1767.0			1690.0	-77.0
1.1	Ejection Structure			80.0		
1.1	Docking Hatches		85.0			
1.5	Ascent Tank Shielding		40.0			
1.9	Separation System		32.0			
2.0	Stabilization and Control	90.5			89.0	- 1.5
2.2	Ascent Programmer		1.5			
3.0	Navigation and Guidance	216.0			191.0	-25.0
3.1.2	OMU		7.0			
3.1.7	Chart Book and Catalog		2.0			
3.2	Radar (Laser and Antenna)		36.0			
	Radar Altimeter and Antenna			20.0		
4.0	Crew Systems	874.2			968.2	+94.2
4.1.2	Portable Life Support System		50.0			
4.1.3	Personal Radiation Dosimeter (2)		5.0			
4.3	Seats and Restraints (2)		70.0			
4.3	Ejection Seats (2)			280.0		
4.4.22	Motion Picture Cameras (2)		16.0			
4.5.1	Water		26.4			
4.5.2	Food		5.6			
4.5.3	Tubes		3.0			
4.5.4	Storage Cabinet		1.5			
4.5.5	Heat Exchanger		4.5			
4.5.6	First Aid Equipment		2.0			
4.5.8	Telescope Seal		2.0			
5.0	Environmental Control	403.1	403.0	122.1	122.1	-280.9
6.0	Landing Gear	312.0	312.0	576.0	576.0	+264.0

DERIVATION OF STRIPPED WEIGHT (Cont'd)

Code	Item Removed/ Added	Gross Weight (LEM)	Less	Plus	Net	Δ Weight
7.0	Instrumentation	436.3			170.3	-266.0
7.1.5	Still Camera		6.0			
7.1.6	Telescope		10.0			
7.3	Scientific Instruments		250.0			
Note: assume trade-off for remainder of Instrumentation						
8.0	Electrical Power Supply	416.8			172.0	-244.8
8.1	Fuel Cell Modules and Batteries		314.8			
8.1	Batteries 28V. for .5 Hr. at 1.5 KW.			70.0		
9.0	Propulsion	17066.2			602.7	-16463.5
9.1	Propellant		15558.0			
9.2.1	Fuel Tanks-Ascent		38.0			
9.2.2	Fuel Tanks-Descent (2)		86.0			
9.2.3	Oxidizer Tanks-Ascent		52.0			
9.2.4	Oxidizer Tanks-Descent (2)		120.0			
9.2.5	Plumbing-Ascent		50.0			
9.2.6	Plumbing-Descent (10%)		20.0			
9.3.1	Press. Tanks and Gas-Ascent		100.0			
9.3.2	Press. Tanks and Gas-Descent (2)		210.0			
9.3.3	Press. Plumbing-Ascent		30.0			
9.3.4	Press. Plumbing-Descent (2/3)		60.0			
9.4.1	Ascent Engine		74.2			
9.4.2	Descent Engine (part of skirt only)		65.3			
10.0	Reaction Controls	310.0			160.0	-150.0
10.2	Propellant		150.0			

DERIVATION OF STRIPPED WEIGHT (Cont'd)

Code	Item Removed/ Added	Gross Weight (LEM)	Less	Plus	Net	Δ Weight
11.0	Communications	101.6			26.1	- 75.5
11.2	VHF Transceiver (LEM/Man)		2.0			
11.4	UHF Transceiver (LEM/Earth)		28.0			
11.5	TV Receiver		1.0			
11.6	Portable TV Camera		7.0			
11.7	Portable TV Tracker		16.0			
11.8	Portable TV Transmitter		.5			
11.9	Portable TV Battery		1.0			
11.10	Close Circuit TV		4.0			
11.11	VHF Antenna (LEM/Man)		1.0			
11.13	UHF Antenna (LEM/Earth)		15.0			

SUMMARY

1.	Structure	1767.0	157.0	80.0	1690.0	- 77.0
2.	Stabilization and Control	90.5	1.5	-	89.0	- 1.5
3.	Navigation and Guidance	216.0	45.0	20.0	191.0	- 25.0
4.	Crew Systems	874.2	186.0	280.0	968.2	+ 94.0
5.	Environmental Control	403.0	403.0	122.1	122.1	-280.9
6.	Landing Gear	312.0	312.0	576.0	576.0	+264.0
7.	Instrumentation	436.3	266.0	-	170.3	-266.0
8.	Electrical Power Supply	416.8	314.8	70.0	172.0	-244.8
9.	Propulsion	17066.2	16463.5	-	602.7	-16463.5
10.	Reaction Controls	310.0	150.0	-	160.0	-150.0
11.	Communications	101.6	75.5	-	26.1	- 75.5
	Total	21993.6	18374.3	1148.1	4767.4	-17226.2

TABLE 4-2

LTA-9 GROUP WEIGHT SUMMARY - STRIPPED WEIGHT

Code	Item	Weight
1.0	Structure	(1690.0)
1.1	Crew Capsule	585.0
1.2	Egress Platform	20.0
1.3	Equipment Compartment	130.0
1.4	Lower Bulkhead-Ascent	96.0
	-Descent	159.0
1.5	Engine Compartment	156.0
	Tank Supports-Descent	126.0
1.6	Insulation	60.0
1.7	Upper Bulkhead-Descent	116.0
1.8	Engine Supports-Descent	58.0
1.10	Landing Gear Skirt	184.0
2.0	Stabilization and Control	(89.0)
2.1	Navigation Guidance Coupler	20.0
2.2	Backup Programmer:	
	A. Inertial Reference Unit	25.0
	B. Rate Gyro Package	5.0
	C. Euler Angle Computer	9.0
2.3	Control Electronics	20.0
2.4	Power Supply	10.0
3.0	Navigation and Guidance	(191.0)
3.1.1	Inertial Measuring Unit	60.0
3.1.3	Computer	60.0
3.1.4	Power and Servo Amplifier	25.0
3.1.5	Control and Display Unit	6.0
3.1.6	Cabling and Junction Box	20.0
3.2	Radar Altimeter and Antenna	20.0
4.0	Crew Systems	(968.2)
4.1.1	Space Suits	50.0
4.2.1	Flight Commander	170.0
4.2.2	Systems Engineer	170.0
4.3	Ejection Seats and Restraints	280.0
4.4.1	G.F.E. (Navigation and Guidance)	50.0
4.4.2	G.F.E. (Range Drift Unit)	20.0
4.4.3	Instrument Panel	15.2
4.4.4	Display	158.0
4.5	Miscellaneous Equipment	55.0

LTA-9 GROUP WEIGHT SUMMARY - STRIPPED WEIGHT (Cont'd)

Code	Item	Weight
5.0	Environmental Control	(122.1)
5.1	Compressor	13.1
5.2	Brackets and Plumbing	20.0
5.3	Coolant Fluid	12.0
5.4	Freon	26.0
5.5	Freon Tank	1.0
5.6	Vent Fan	4.8
5.7	Suit Plug-In	3.0
5.8	Ducts and Brackets	2.2
5.9	Miscellaneous	40.0
6.0	Landing Gear	(576.0)
6.1	Wheels and Oleos	400.0
6.2	Struts and Support Structure	176.0
7.0	Instrumentation	(170.3)
7.1.1	Sensors and Signal Conditioner	56.0
7.1.2	Signal Processor	25.0
7.1.3	Clock	8.3
7.1.4	Tape Recorder	16.0
7.2	On-Board Checkout System	65.0
8.0	Electrical Power Supply	(172.0)
8.1	Batteries (2)	70.0
8.2	Distribution System	29.0
8.3	Interconnecting Cables and Supports	73.0
9.0	Propulsion	(602.7)
9.2.2	Fuel Tank	43.0
9.2.4	Oxidizer Tank	60.0
9.2.6	Plumbing	180.0
9.3.2	Pressurization Tank and Gas	105.0
9.3.4	Pressurization Plumbing	30.0
9.4.2	Engine	184.7
10.0	Reaction Controls	(160.0)
10.1.1	Fuel Tanks	6.0
10.1.2	Oxidizer Tanks	8.0
10.1.3	Pressurization Tanks and Gas	18.0
10.1.4	Thrust Chambers (16)	80.0
10.1.5	Plumbing (Propellant)	30.0
10.1.6	Plumbing (Pressurization)	18.0

LTA-9 GROUP WEIGHT SUMMARY - STRIPPED WEIGHT (Cont'd)

Code	Item	Weight
11.0	Communications	(26.1)
11.1	Intercoms (2)	2.5
11.3	VHF Transceiver	3.0
11.12	Antenna-VHF	4.0
11.14	Antenna-UHF	10.0
11.15	Antenna Microwave Components	6.6
	TOTAL	4767.4

X Arm = 210.1

Z Arm = + 9.2

4.2 LTA-9 PRELIMINARY AERODYNAMIC CHARACTERISTICS

4.2.1 Description of Wind Tunnel Test Program

Due to the unconventional LEM configuration with respect to vehicles currently operating in the earth's atmosphere, no practical basis exists for making reasonable engineering estimates of aerodynamic characteristics. In order to obtain "first pass" aerodynamic data for use in development of the LTA-9 atmospheric training vehicle, a series of low speed wind tunnel tests were conducted on a 1/8 scale LEM model. These tests were made at the Grumman Aircraft Engineering Corporation 7 X 10 foot low speed wind tunnel during the period February 1-7, 1963. The purpose of these tests were:

1. To define the aerodynamic characteristics of the LEM as an aid in development of the LTA-9 atmospheric training vehicle.

2. To obtain an insight into possible vehicle buffet conditions arising from operation of the LTA-9 in the earth's atmosphere.

To insure a test program of reasonable length, it was necessary to restrict the investigation to the basic vehicle characteristics without the complication of simulating jet exhausts. These effects were considered secondary at this stage of the investigation as various practical considerations (levitation system installation, degraded reaction control performance in an atmospheric environment, etc.) will require modification of the LEM to obtain the LTA-9 configuration. The tests were conducted at a simulated full scale Reynold's number equivalent to a velocity of 31 fps for the complete test program. This selection was dictated by the maximum speed capability of the wind tunnel and is representative of a reasonable speed for a good portion of the LTA-9's operation.

The model was sting mounted for this series of tests; forces and moments were obtained from the tunnel balance system. In addition the model was tufted for visual and photographic observation of turbulent and separated areas. A series of typical tuft observations are presented in figures 4.1 and 4.2. The model was provided with an orthogonally mounted set of accelerometers aligned along the X, Y, Z body axes within the model. The purpose of these accelerometers were to obtain a rough order of magnitude evaluation of possible vehicle buffet which might arise under full scale conditions; results are presented in figures 4.3 through 4.5. The aerodynamic force and moment characteristics of the LEM are presented in figures 4.6 through 4.8 for a velocity range of zero to 100 fps. These data were calculated from wind tunnel test results presented in Grumman Wind Tunnel Test Report 174(323-1). Photographs of the 1/8 scale LEM model installed in the wind tunnel test section are presented in figures 4.9 and 4.10.

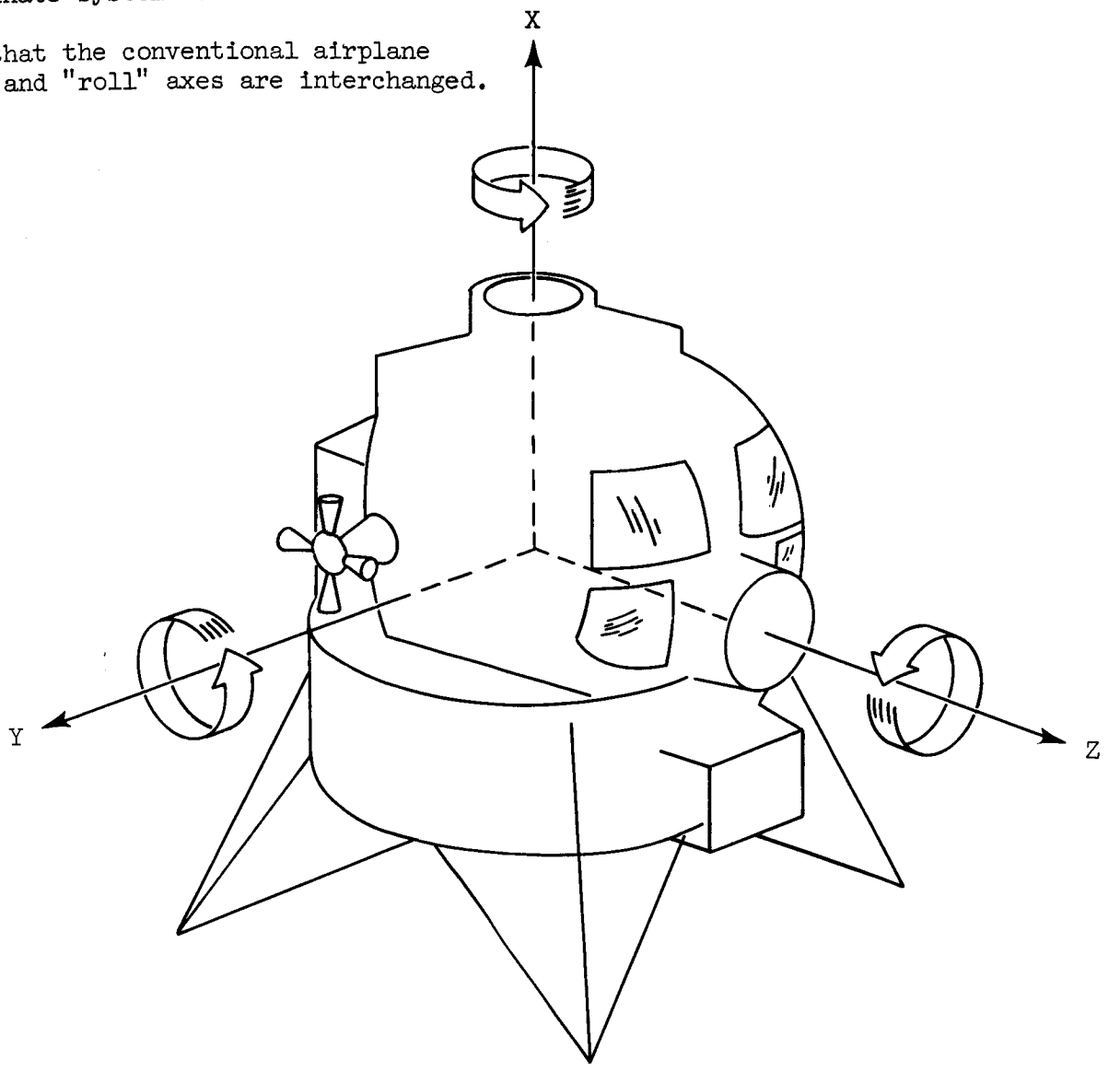
4.2.2 Summary of Results

The aerodynamic forces and moments of the LEM exhibit definite non-linear characteristics along and about the body axes in the pitch condition (figure 4.6 through 4.8) throughout the range of attitudes tested. The magnitude of these forces and moments appear reasonable through the speed range encompassing the LTA-9 mission and should not impose any force or trim compensating problems which cannot be satisfied by the Earth Environment Compensation system discussed in section 5.0 of this study report.

A brief investigation of the possible buffet characteristics of the LEM vehicle was conducted utilizing, 1) a tufted model and observing flow turbulence and separation areas, 2) an orthogonally mounted set of accelerometers aligned along the X, Y, Z body axes within the model. Prior calculation of the Karman shed vortex frequencies and the natural frequencies of the model + support system indicated they would be of the same order of magnitude. Initial impulses of the model were made at zero airspeed to obtain the natural frequencies of the model + support system. The predominant frequencies measured during the force runs coincided as expected with the natural frequencies of the model + support. Assuming that the amplitude of the resulting accelerations are a direct result of the strength of the turbulence being shed by the model, and thus a qualitative measure of the buffet level expected full scale, a comparison was made of the maximum accelerations in figures 4.3 through 4.5. It should be noted that the ordinates are scaled in "model g's" and should not be used as buffet intensities expected on the LTA-9. These figures should be used as trends and order of magnitude changes only. It should also be realized that extraneous inputs are obtained from tunnel vibrations and inherent turbulence levels of the tunnel flow. Figures 4.3 through 4.5 for the gear-on configuration indicate an amplitude buildup at -20° angle of attack which is approximately double that measured at zero angle of attack. It is also noted that gear removal reduces the measured accelerations. As can be seen the measured amplitudes vary, through the pitch range, indicating varying aerodynamic inputs and most probably changing buffet levels. The use of model mounted accelerometers for predicting buffet conditions is limited by the inability to correlate with full scale conditions, however, the results are useful in the evaluation of configuration changes or determining qualitative order of magnitude changes.

In summary, the aerodynamic characteristics of the LTA-9 vehicle are expected and assumed to be similar to the LEM model tested, the results of which do not indicate any serious force and moment compensating problems. Additional testing during the follow-on development phase is anticipated to fully explore the effects of Reynold's Number, jet exhaust and other configuration variables.

For purposes of this study the LEM coordinate system defined below is used.
Note that the conventional airplane "yaw" and "roll" axes are interchanged.

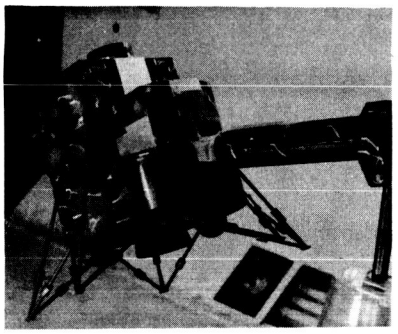


Forces	X-Axis	Y-Axis	Z-Axis
Momments	Roll	Pitch	Yaw
Angles	ϕ	θ	ψ

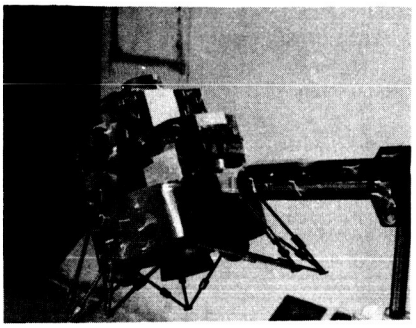
Definition Of Coordinate System

TUFT STUDIES IN PITCH

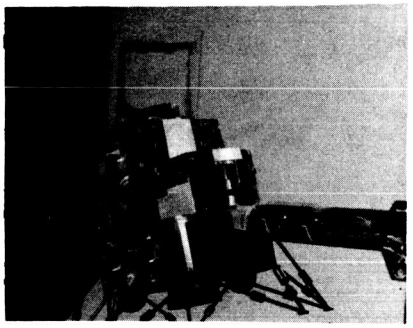
MODEL ANGLE OF ATTACK FROM α = -30° to +60°



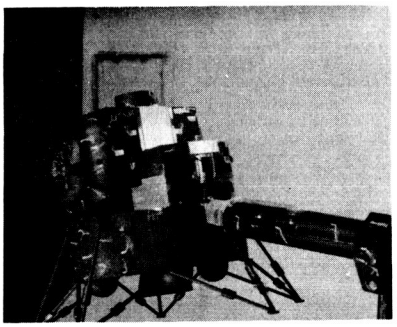
α = -30° Run 19



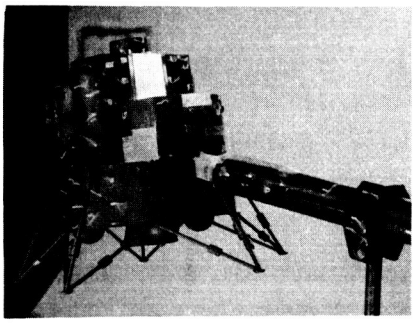
α = -25°, Run 19



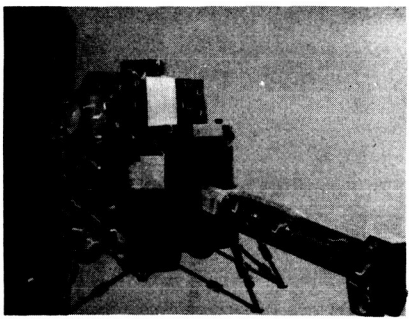
α = -20°, Run 19



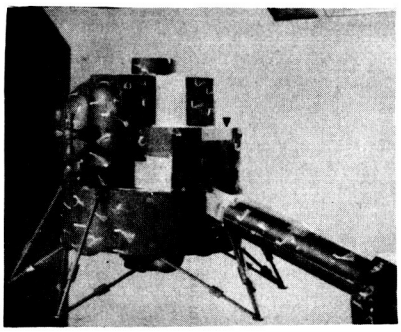
α = -15°, Run 19



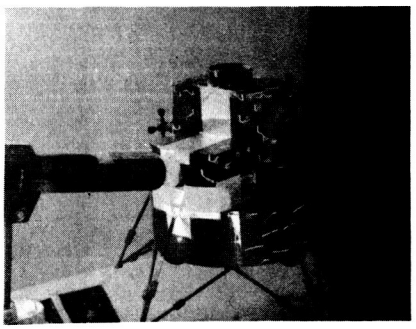
α = -10°, Run 19



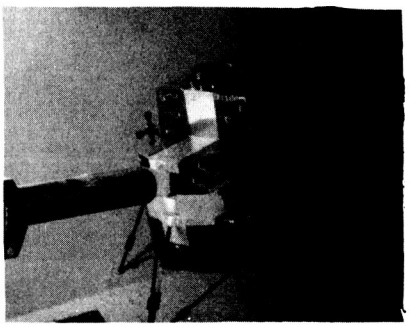
α = -5°, Run 19



α = 0°, Run 19



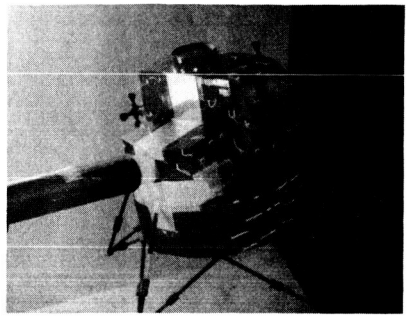
α = +5°, Run 16



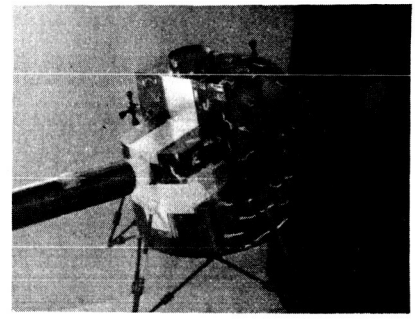
α = +15°, Run 16

Fig. 4-1

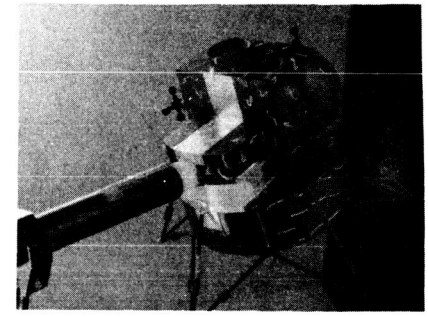
TUFT STUDIES IN PITCH (Cont.)



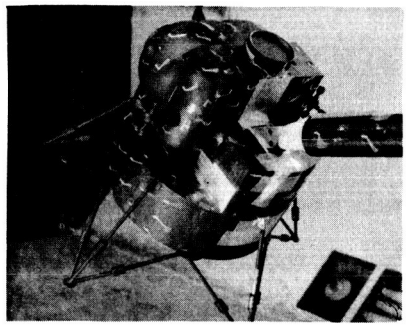
α = +20°, Run 16



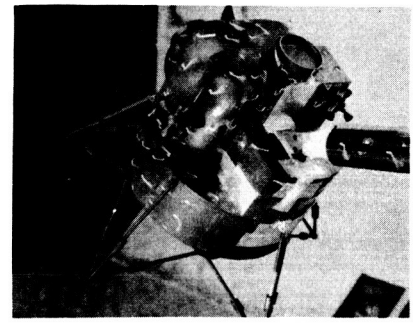
α = +25°, Run 16



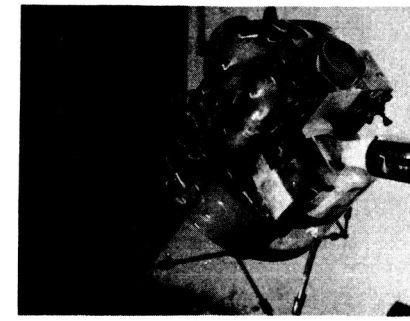
α = +30°, Run 16



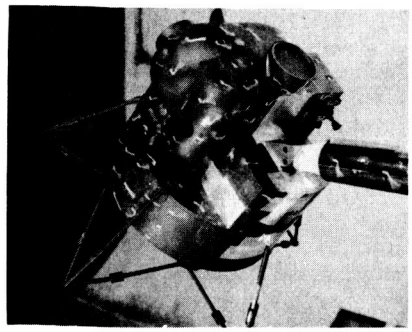
α = +35°, Run 18



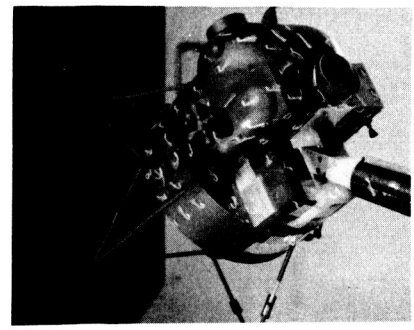
α = +40°, Run 18



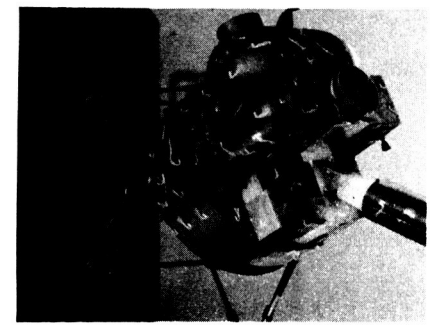
α = +45°, Run 18



α = +50°, Run 18

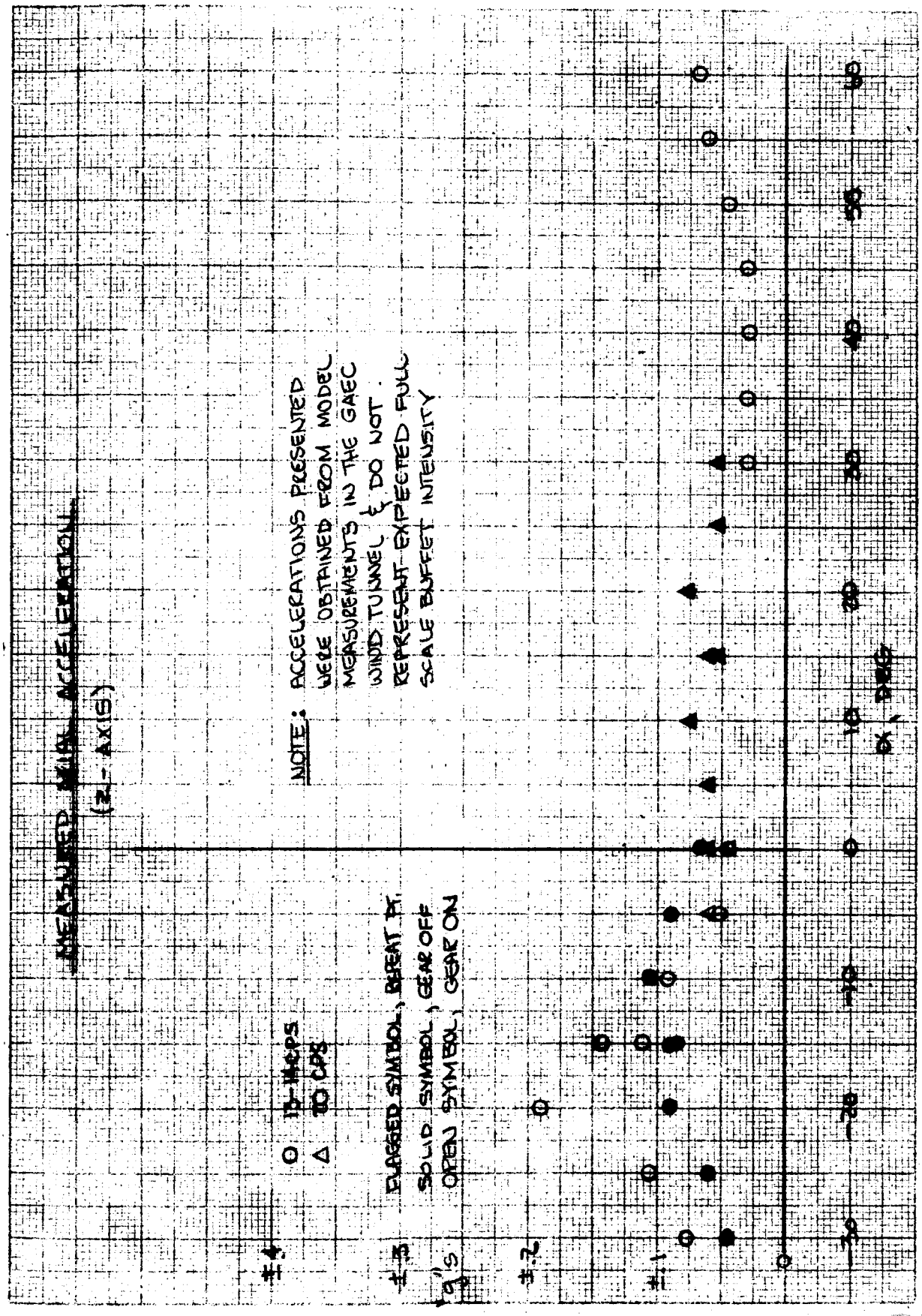


α = +55°, Run 18



α = +60°, Run 18

Fig. 4.2


MEASURED WING ACCELERATION
(Z - AXIS)
NOTE: ACCELERATIONS PRESENTED WERE OBTAINED FROM MODEL MEASUREMENTS IN THE GAEC WIND TUNNEL & DO NOT REPRESENT EXPECTED FULL SCALE BUFFET INTENSITY
O 10 KEPS
△ 20 CPS
FLAGGED SYMBOL, BEAT FT.
SOLID SYMBOL, GEAR OFF
OPEN SYMBOL, GEAR ON
#4
#3
#2
#1
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
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300
310
320
330
340
350
360
370
380
390

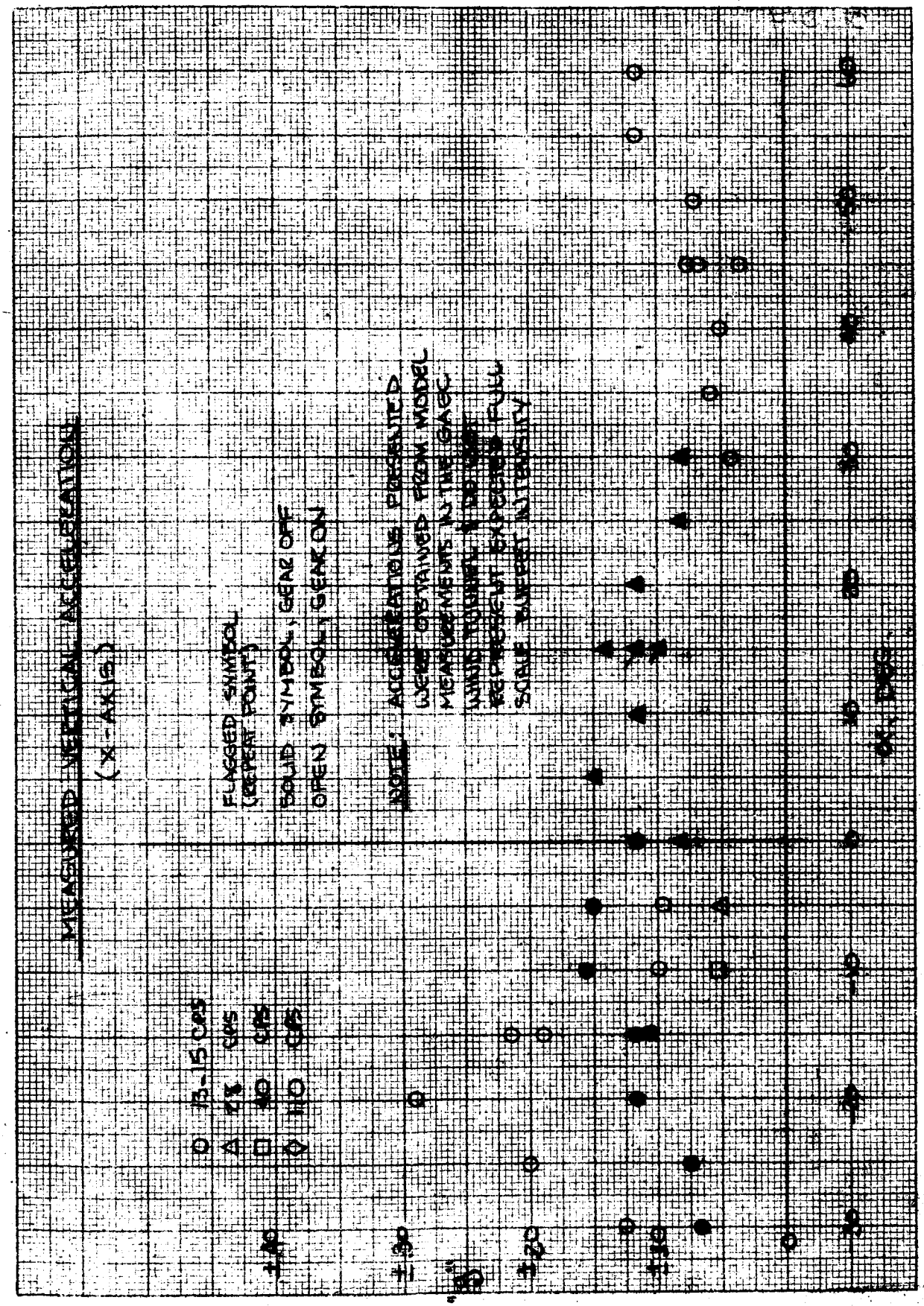

MEASURED VERTICAL ACCELERATION
(X-AXIS)
FLAGGED SYMBOL
(DEFECT POINTS)
SOLID SYMBOL, GEAR OFF
OPEN SYMBOL GEAR ON
NOTE: ACCELERATIONS PRESENTED
GIVEN OBTAINED FROM MODEL
MEASUREMENTS AT THE GAGE
WHICH PRODUCED
REPRESENTATIVE EXPERIENCE FULL
SCALE FLIGHT
3-5 CPS
4.5 CPS
7.0 CPS
11.0 CPS
+40
+30
+20
+10

Fig. 4-4

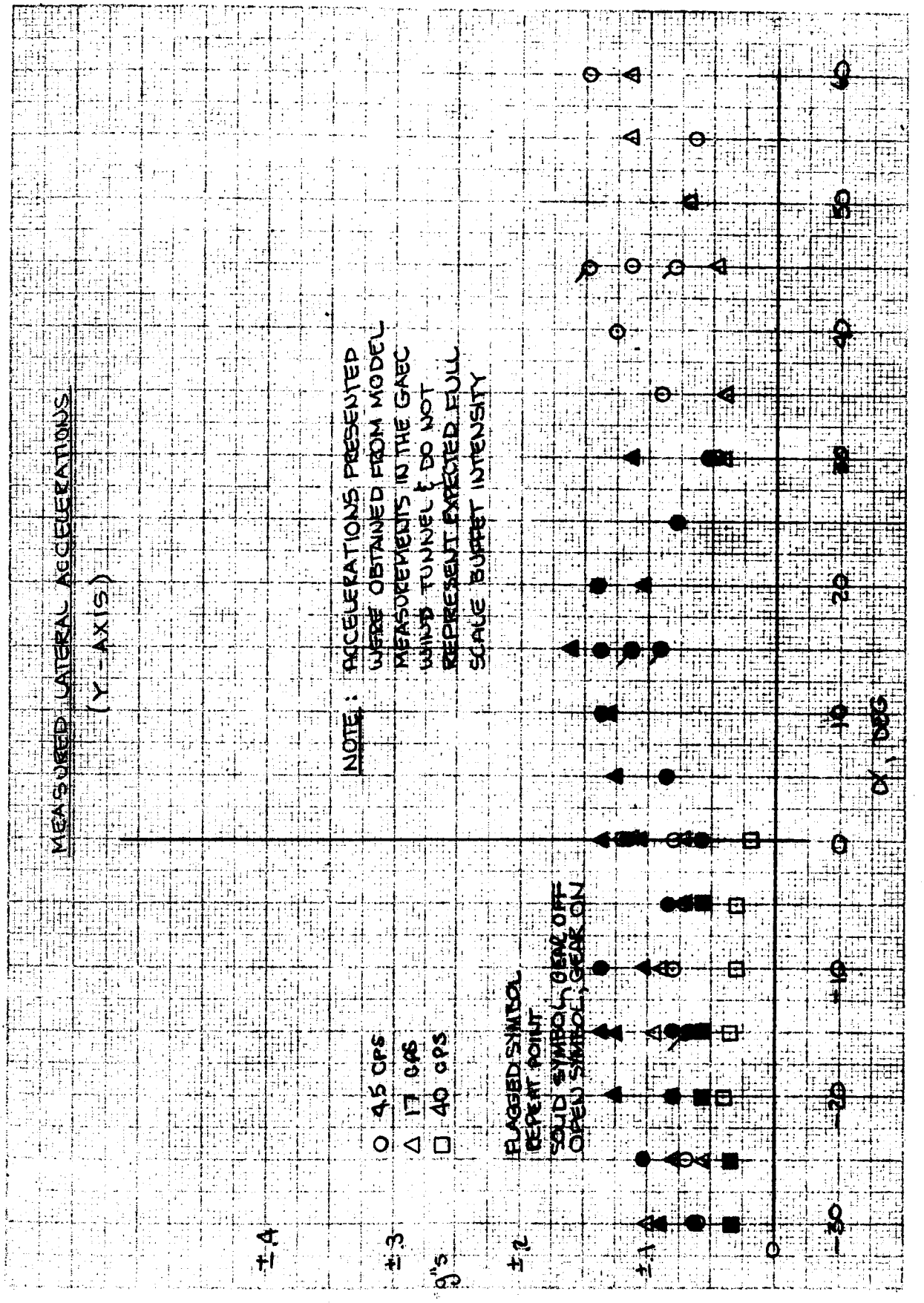

MEASURED LATERAL ACCELERATIONS
(Y - AXIS)
NOTE: ACCELERATIONS PRESENTED WERE OBTAINED FROM MODEL MEASUREMENTS IN THE GAEC WIND TUNNEL & DO NOT REPRESENT EXPECTED FULL SCALE BUFFET INTENSITY
○ 45 CPS
△ 17 CPS
□ 40 CPS
FLAGGED SYMBOL DEPART POINT
SOLID SYMBOL GEAR OFF
OPEN SYMBOL GEAR ON
g's
±4
±3
±2
±1
0
-10
-20
-30
+10
20
30
40
50
α, DEG

Fig. 4-5

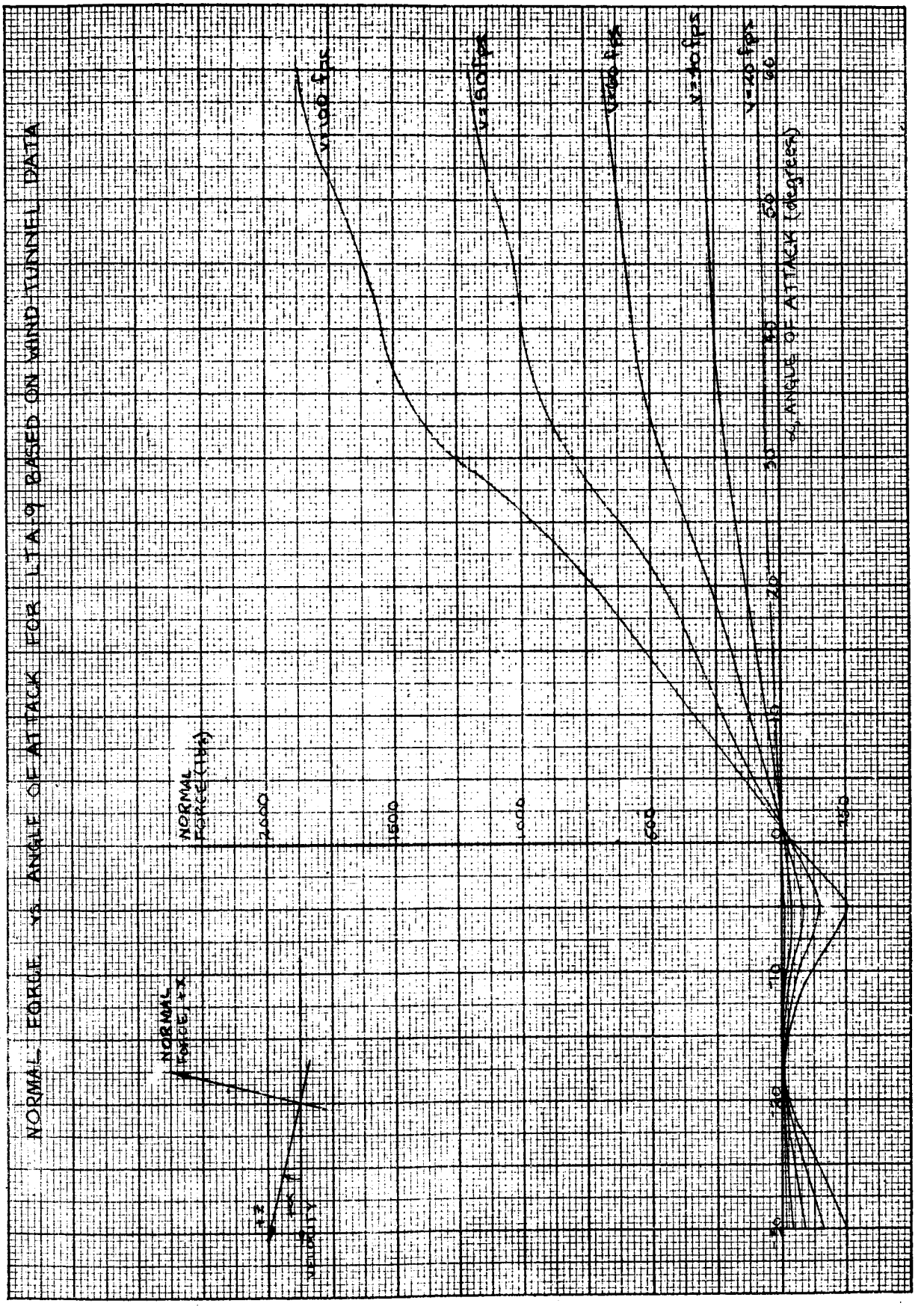
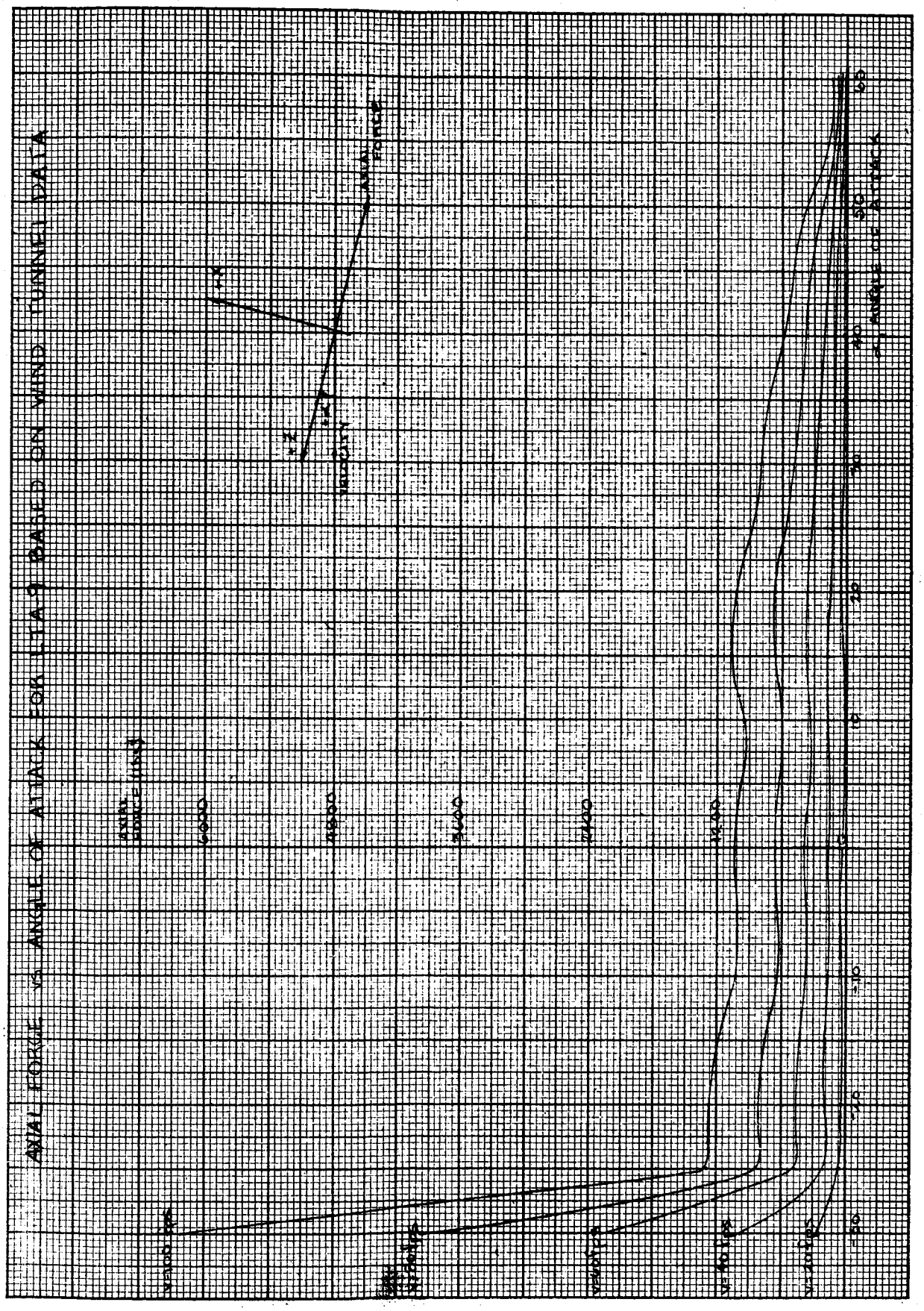


Fig. 4-6

Grumman LEM


AXIAL FORCE vs ANGLE OF ATTACK FOR LEM-9 BASED ON WIND TUNNEL DATA
AXIAL FORCE
ANGLE OF ATTACK
VELOCITY
ALTITUDE
AXIAL FORCE - LBS
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
-8000
-9000
-10000
-11000
-12000
-13000
-14000
-15000
-16000
-17000
-18000
-19000
-20000
-21000
-22000
-23000
-24000
-25000
-26000
-27000
-28000
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-38000
-39000
-40000

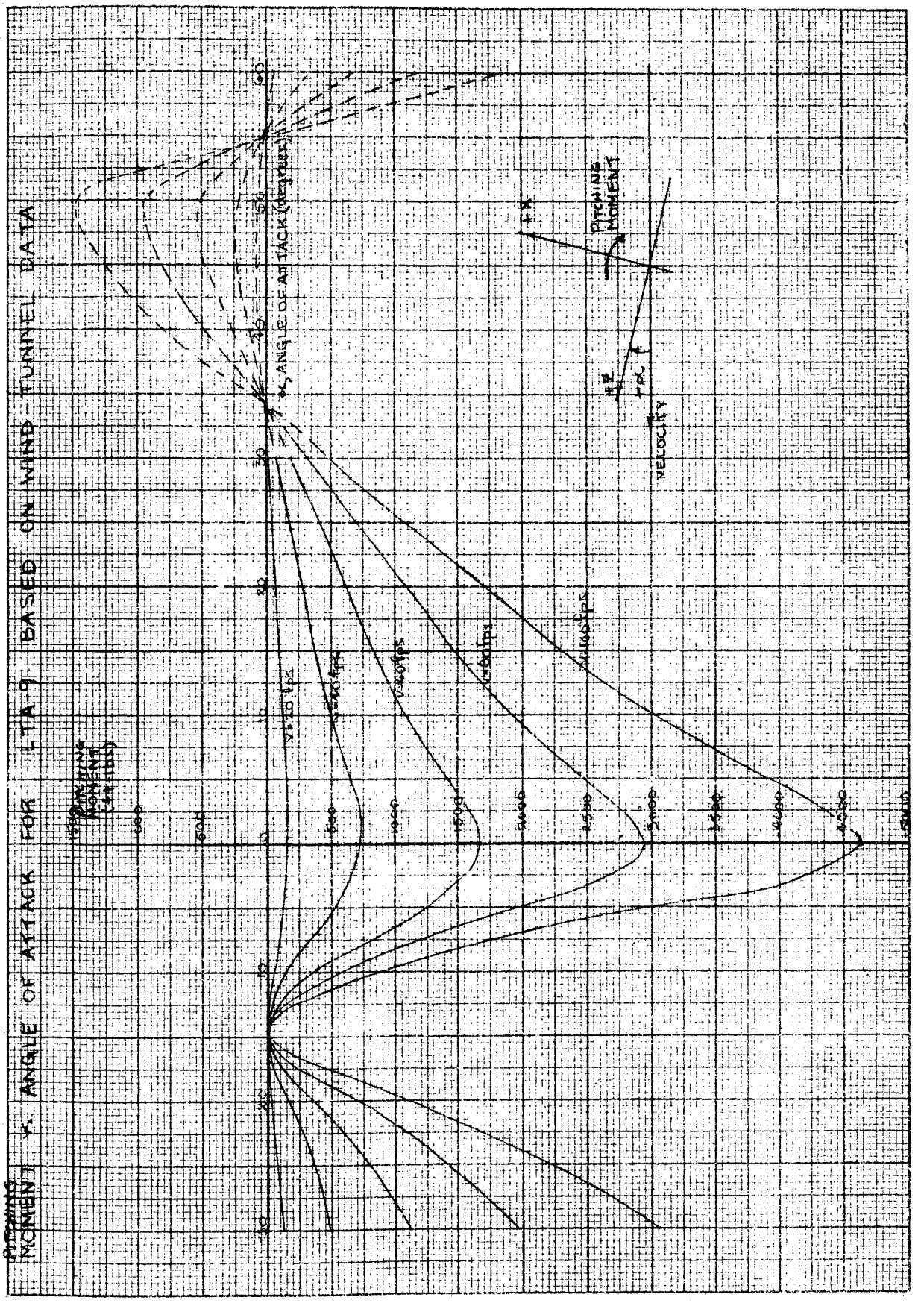

PITCHING MOMENT VS. ANGLE OF ATTACK FOR LTA-9 BASED ON WIND-TUNNEL DATA
PITCHING MOMENT (ft-lbs)
ANGLE OF ATTACK (degrees)
+α
+M
PITCHING MOMENT
VELOCITY
V=20 fps
V=40 fps
V=60 fps
V=80 fps
V=100 fps

Fig. 4-8

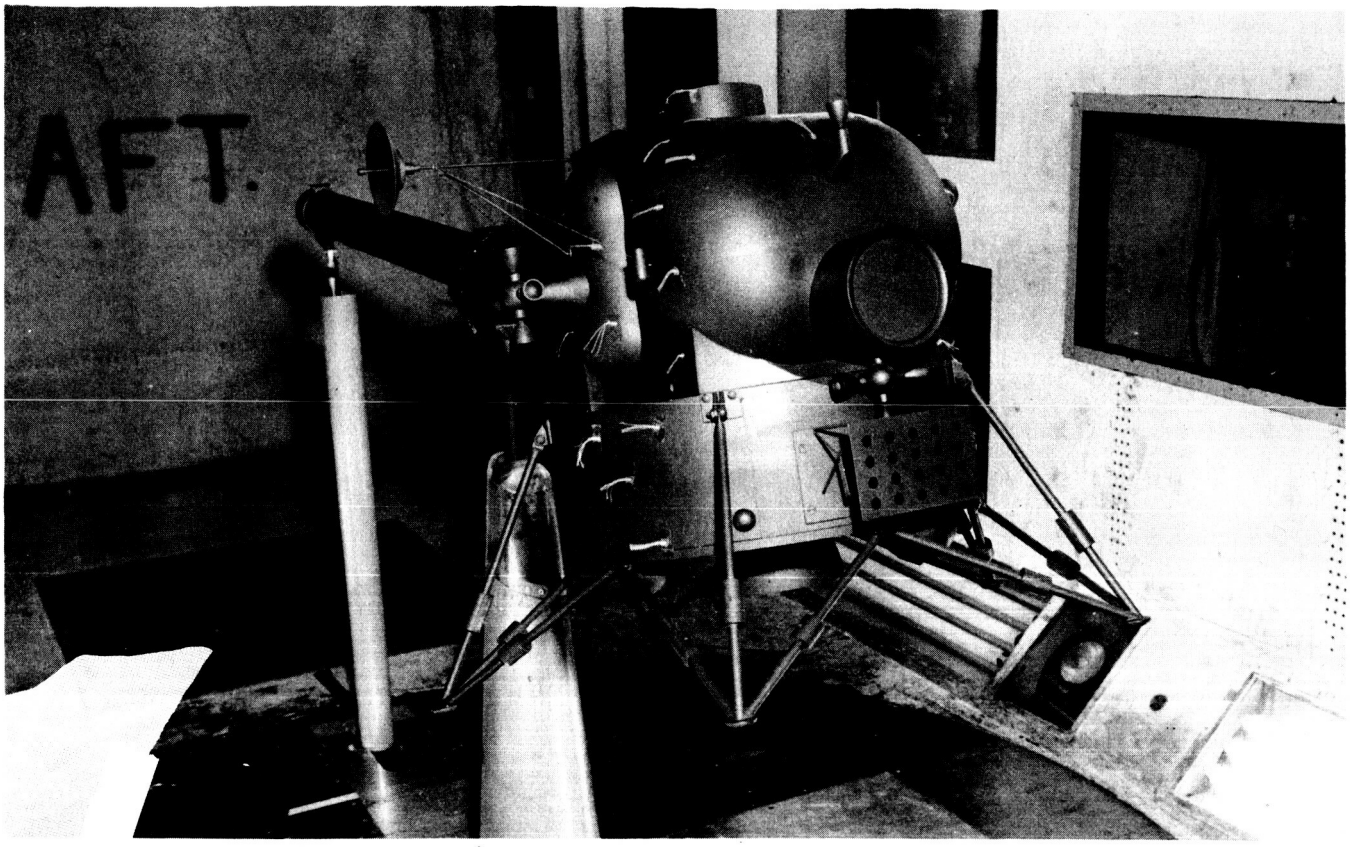


Fig. 4.9

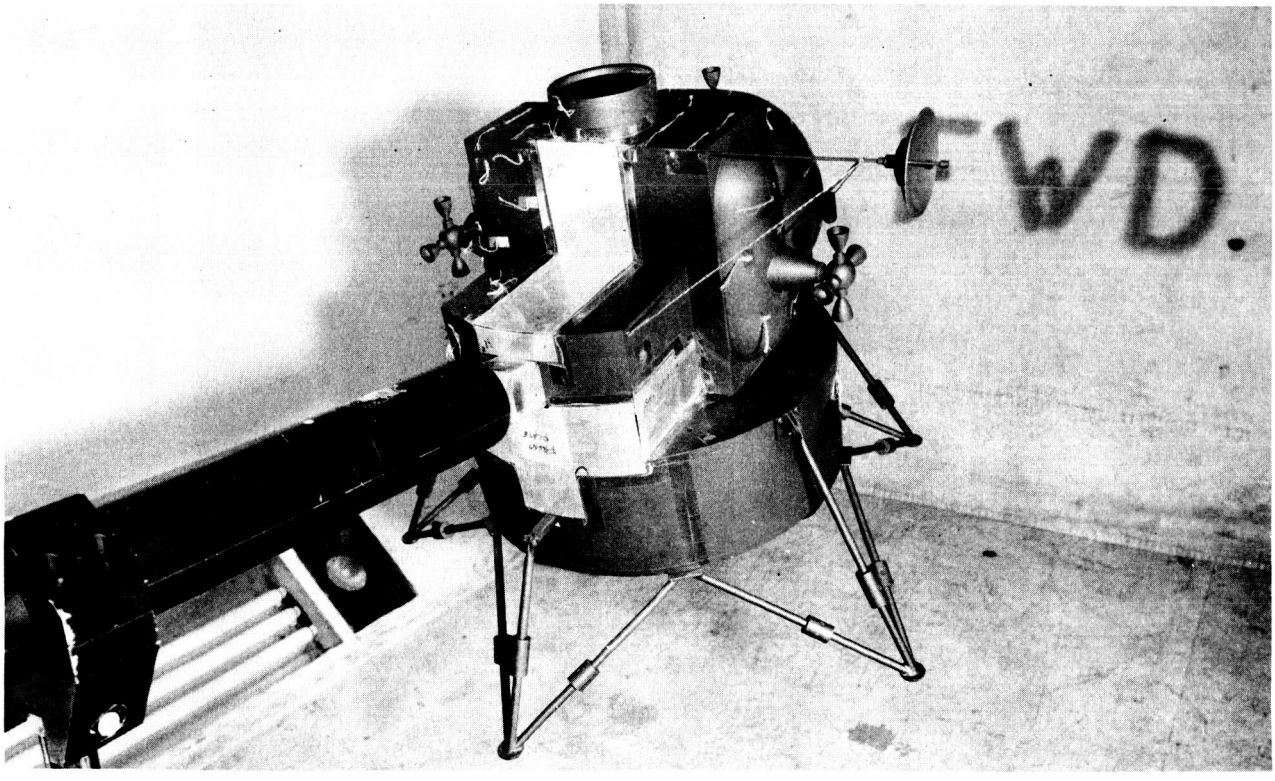


Fig. 4.10

1/8-Scale LEM Module. Above, 3/4 Right Front View. Below, 3/4 Right Rear View.

4.3 LEM DESCENT ENGINE AND RCS MODIFICATIONS

A design ground rule of the LTA-9 vehicle is to use all LEM components required during terminal descent. Therefore, the LEM RCS and descent propulsion system are retained. Since both of these systems have been designed to operate only in a vacuum, certain modifications must be made to permit operation in the atmosphere. The extent of the modifications required depends on the system performance necessary to satisfy the various configurations investigated.

Two approaches are considered for modification of the LEM descent propulsion rocket engine. The first approach is based on use of auxiliary jet "levitation" engines (Earth Environment Compensation System) to support 5/6 of the vehicle's weight. The second calls for the use of a single rocket engine to support the total vehicle weight during atmospheric free flight. Engine modifications required in each case are described below.

4.3.1 Modification of Descent Engine Used With Earth Environment Compensation System (EEC)

When used in conjunction with an EEC system, the descent engine must produce the same thrust as it would during the lunar terminal landing maneuver while the remainder of the supporting thrust (about 5/6 of the vehicle weight) is being supplied by a separate levitation system. Hence the nominal thrust of the descent engine during the terminal landing maneuver is in the order of 1700 pounds (10,000/6). The minimum rocket thrust level is governed by the requirement to provide the same rocket thrust-to-vehicle mass ratio as on the lunar surface. Although theoretically it is possible to provide the correct sink rate by reducing the levitation thrust, this approach would not provide realistic simulation of the lunar rocket thrust changes. Thus the minimum thrust output of 1050 pounds of the LEM descent engine is retained for LTA-9.

It is desired to minimize descent engine modifications to reduce cost and time of man-rating. Hence, the only modification contemplated for this configuration involves a reduction of the engine expansion ratio for atmospheric operation. The engine nozzle will be physically cut off at an expansion ratio of 2.3:1. This provides the required minimum thrust value of 1050 pounds without going below the Summerfield criteria of separation ($P_{exit}/P_{amb} = .29$). Maximum thrust for this modified expansion ratio is 7100 pounds at a 5,000 foot pressure altitude.

A byproduct of the reduction in expansion ratio involves a modification of the gimbal ring attachment since the present gimbal ring mounts at an expansion ratio of about 6:1. If this ratio were maintained, it would result in a minimum stable thrust of about 6,000 pounds.

Table 4.3 compares the pertinent characteristics of the LEM descent engine with the same engine modified for atmospheric operation. Performance is based on 5,000 feet pressure altitude. The maximum thrust shown is based on maintaining the chamber pressure of 125 psi used in the LEM descent engine. Figure 5 shows the variation of specific impulse with thrust. The reduction of impulse from the same thrust level in vacuum is reflected in a considerable increase of rocket propellant required for the terminal maneuver. Thus, for a given initial mass of 310 slugs, the propellant required by the atmospheric engine is about 2.4 times the propellant required in a vacuum.

Since modification of the engine is minimal, no major development effort is required beyond requalification of the thrust chamber with the new expansion ratio. The anticipated development program will dovetail into the LEM descent program.

A preliminary weight estimate from Rocketdyne indicates that the modified engine will weigh about 197 pounds. Nominal engine thrust level, to hover, based on the weight of the conceptual LTA-9 design shown in figure 6.5 varies from 1615 lbs. at the beginning of descent to 1280 lbs. at touchdown.

Information from Rocketdyne indicates that cutting off a 40:1 nozzle will result in a wide divergence angle (32.3 degrees). Some thrust loss will be suffered due to the greater radial momentum of the gases. This amounts to 6.3% more loss than an optimum nozzle design. A second effect of the wide divergence will be a greater tendancy for the jet to separate during low chamber pressure operation at sea level.

Minimum thrust chamber design life will be 480 seconds for the defined duty cycle.(Nominal thrust of 2,000 lbs. and two minutes per run).

TABLE 4.3

DESCENT ENGINE CHARACTERISTICS (GRUMMAN CALCULATIONS)

	LEM (Vacuum Operation)		LTA-9 (Atmospheric Operation)	
	Max. Throttle	Min. Throttle	Max. Throttle	Min. Throttle
Expansion Ratio	40:1	40:1	2.3:1	2.3:1
Chamber Pressure-P_c psia	125	12.5	125	36
Ambient Pressure-P_{amb} psia	0	0	12.25	12.25
P_c/P_{amb}			10.2	2.95
Thrust coefficient-C_f	1.88	1.88	1.27	.65
P_{exit}/P_{amb}			1.00	.29
Thrust-lbs.	10,500	1,050	7100	1050
Specific Impulse Sec.	305	290	206	105

4.3.2 Modifications Required for All-Rocket Configuration

An alternate propulsion approach for LTA-9 is the use of the descent engine to provide all the lift required to sustain the vehicle. Section 5.3 indicates that a mission of reasonable flight time requires a maximum thrust of about 12,000 pounds. Since it is desired to retain the LEM propulsion system, this approach requires a modified "battleship" descent engine to provide the desired 12,000 pounds thrust in atmospheric operation. Minimum thrust required is about 5,000 pounds. To achieve this thrust range with a descent-type engine requires either an increase in chamber pressure or a larger throat diameter. Even though this engine retains the gimbal scheme, cooling, propellant combination, and throttling method of the basic descent engine, additional development is required to qualify the engine for manned flight. Budgetary information from Rocketdyne indicates that development cost of the "battleship" engine will be greater than that of the engine used in conjunction with a "levitation" system. Rocketdyne estimates that the total assembly weight of a throttleable "battleship" engine having a maximum thrust capability of 12,000 pounds will be approximately 280 pounds. No cooling problems are anticipated with the ablatively-cooled chamber. The thrust chamber is designed for a minimum life of 480 seconds.

4.3.3 Rocketdyne Information

A summary of nominal engine characteristics for each of the approaches discussed above has been furnished by Rocketdyne and is presented in table 4.4 : "Thrust Chamber No. 1" refers to the modified LEM engine to be used with a "levitation" system. "Thrust Chamber No. 2" refers to the all-rocket application. Values shown for Thrust Chamber No. 1 differ slightly from Grumman preliminary calculations. The differences arise in selection of modified expansion ratio and maximum chamber pressure. Generally, however, the Rocketdyne values corroborate Grumman results.

TABLE 4-4

SUMMARY OF NOMINAL ENGINE

CHARACTERISTICS

PERFORMANCE	THRUST CHAMBER # 1	THRUST CHAMBER # 2
Thrust, lbs		
at 150 psia, S.L.	6,459	12,000*
at 150 psia, 10,000 ft.	6,880	12,647
at 150 psia, vacuum	7,809	14,076
at 75.4 psia, S.L.		5,000*
at 64.4 psia, S.L.	2000*	
at 46.1 psia, S.L.	1050*	
Specific Impulse, Seconds		
at 150 psia, S.L.	190.9	203.9
at 150 psia, 10,000 ft.	203.2	214.8
at 150 psia, vacuum	230.7	238.0
at 75.4 psia, S.L.		168.1
at 64.4 psia, S.L.	137.7	
at 46.1 spia, S.L.	100.9	
Geometric Dimensions		
Characteristic Length, in.	42	38
Contraction Area Ratio	2.5	2.54
Contraction Angle	20°	20°
Expansion Area Ratio	2.45	2.17
Type of Nozzle	70% Bell (40:1) Cutoff at 2.45:1	15° Cone
Throat Area, in^2	37.51	65.4
Inside Diameters, in.		
Combustion Chamber	10.90	14.50
Exit Nozzle	10.83	13.42
Total Length, in.	23.28	27.90

* Design Value

4.3.4 LEM RCS Modifications for Atmospheric Operation

The modifications of the RCS are essentially the same as those required by the LEM Descent engine; namely, the nozzle expansion ratio has to be reduced to prevent over-expansion when the system is operating against atmospheric pressure. Two different modification approaches have been investigated and are listed on table 4-5.

In the first approach, the chamber pressure and geometry are maintained at their existing value with the nozzle cut back to an expansion ratio of 1.6 to maintain stable operation. This reduces the thrust per nozzle to 60 pounds.

To maintain the same reaction moments as on LEM the nozzles have to be located 66% further outboard from their present position. This revision requires extension of the propellant feed system and redesign of the nozzle mount structure.

A disadvantage of this approach is that it does not provide the proper thrust magnitude when the RCS is used in the translational mode. However, these forces may be augmented by the EEC system.

A second approach consists of maintaining the thrust level at 100 pounds by increasing the chamber pressure to 135 psia. This will result in an expansion ratio of 2.1. The present chamber may be capable of operating at this increased pressure but may require an injector modification.

At this higher chamber pressure there may be a cooling problem since radiation cooling is used exclusively in the RCS thrusters. This problem can be eliminated by maintaining the present chamber pressure and increasing the throat area. The latter approach, however, would involve a new RCS thruster development and is consequently not advisable. Maintaining proper thrust by a chamber pressure increase has been tentatively assumed for conceptual design pending further information from the Marquardt Corporation.

TABLE 4-5

RCS MODIFICATIONS FOR ATMOSPHERIC OPERATION

	LEM	LTA-9	
		Existing Chamber Pressure	Modified Chamber Pressure
Expansion Ratio	40:1	1.6:1	2.1:1
Thrust - Pounds	100	60	100
Sp. Impulse (steady-state)	305	180	200
Chamber Pressure - psia	90	90	135*
Terminal Descent Propellant - Pounds	23	50	45

* Possible cooling problem for chamber pressures above 100 psia

5. EARTH ENVIRONMENT COMPENSATION (EEC) SYSTEM

5.1 SYSTEM FUNCTIONAL REQUIREMENTS

The LTA-9 control subsystem must provide two modes of operation. First, it must be capable of complete control of the vehicle in free flight. In addition, the subsystem must automatically cancel forces and moments acting on the vehicle that are attributable to differences between the earth and the moon flight environments. More explicitly, during the simulated lunar terminal trajectory with LEM RCS and descent propulsion operative, atmospheric and earth gravitational inputs must be kept below the pilot's threshold.

The EEC system for LTA-9 has been synthesized to reproduce LEM handling qualities in a lunar landing and provide for crew safety during LTA-9 flight operations. From takeoff to a hover point at which the LEM descent will be initiated, flight will be controlled by manual inputs into the compensating sybsystem. At the hover altitude the LEM control systems are started, EEC initial conditions set up, and the earth environment compensating subsystem is put in automatic mode. During the terminal descent and landing the crew will be flying a "LEM" that will show the same flying qualities on earth that the LEM has on the moon.

A formal analysis of the conceptual EEC control system design has indicated that the EEC system:

* performance requirements are well within the limits of available hardware.
* is stable for all modes of operation.
* achieves satisfactory response in conjunction with the desired level of stability and state-of-the-art components.

5.2 EEC SYSTEM ELEMENTS

The three major elements of the earth environment compensation system are the:

* Levitation Engines
* Auxiliary Moment Control
* Flight Control Section

As indicated in Section 5.1 the flight control section is capable of automatic compensation for the simulated LEM lunar landings as well as handling all normal and emergency LTA-9 flight tasks.

The levitation engines in conjunction with the LEM descent engine enable translational acceleration simulation. Auxiliary moment control and rotational acceleration is provided by the levitation engine bleed-air trim system. The elements listed above are described in detail in the following sections.

5.3 LEVITATION ENGINE STUDY

The basic function of the levitation engine system is to supply a vertical thrust equal to 5/6 of the vehicle weight. In addition, the system must be capable of counteracting the aerodynamic forces (and possibly moments) that act upon the vehicle. For emergency use and initial training the levitation system must be capable of supporting the entire vehicle weight and provide excess thrust for vertical acceleration.

From the above description, almost any VTOL lift-system is applicable. However, when it is taken into account that the levitation thrust vector must be capable of rapid changes of magnitude and direction plus the physical restriction of maintaining the thrust gimbal point in the plane of the c.g., the most "efficient" hover lift schemes such as rotors, propellers, and lift fans are eliminated. Thus the only practical levitation systems appear to be compact jet and rocket engines.

A review of the various engine characteristics and detailed configuration studies show the only configuration that provides adequate installed thrust and does not present severe gyroscopic problems is the horizontal-opposed installation of six General Electric SJ-132 engines. The SJ-132 is a developed variation of the J85 engine and qualified engines will be readily available for the program. This version of the LTA-9 provides engine-out capability, has an adequate bleed-air supply for the trim system, eliminates gyroscopic moments, and uses engines of relatively low cost.

5.3.1 Study Description

In order to obtain a valid performance comparison between various simulation systems, a reasonable set of ambient operating conditions has to be established. This is particularly true for the jet levitation system, since the static thrust of jet engines decays rapidly with altitude and temperature as shown in figure 5.1. It is envisioned at present to do the majority of flight testing and training at the White Sands Missile Range (WSMR) due to the availability of the proper rocket propellant handling and storage facilities. Thus, all heights are based on a nominal 4000 foot pressure altitude datum.

Table 5.1 is a reproduction of the monthly temperature variation at WSMR. For purposes of this study the annual mean of the maximum mean monthly temperature (74.9°Fahr) was selected. This temperature corresponds to a value 30° Fahr above the Standard Day Atmosphere and is commonly referred to as "Tropical atmosphere" per MIL-STD-210A. The tropical atmosphere profile was used throughout this study.

Terrain altitude = 4000 ft. above S.L.

The preliminary mission profile requires an initial climb to an altitude of 1000 feet in one minute. Figure 5.2 shows that this can be achieved with an initial thrust-to-weight ratio of 1.075 without exceeding a reasonable and safe rate of climb of 20 feet per second. The data presented in this figure takes into account the reduction in jet engine thrust with altitude, the change of vehicle weight due to fuel consumed, and the effect of aerodynamic and engine ram drag. With these effects, the initial T/W = 1.075 decays to a minimum of 1.035. Since this ratio is considered marginal for control of the vehicle, a T/W of 1.10 was chosen. This provides a minimum ratio of 1.055 and reduces slightly the time required to reach the 1000 foot altitude.

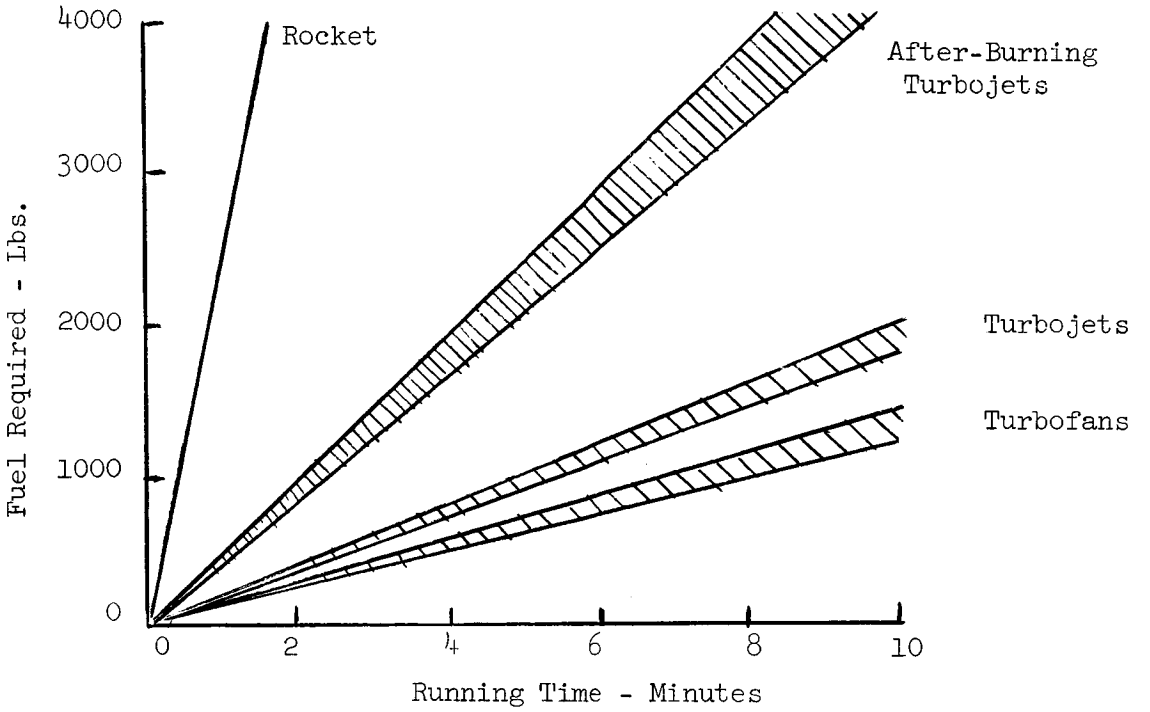
TABLE 5.1

MEAN MONTHLY MAXIMUM AND MINIMUM TEMPERATURE - WHITE SANDS MISSILE RANGE

Month	Mean Monthly Temp. Max.	Mean Monthly Temp. Min.
JAN	56	35
FEB	60	37
MAR	66	44
APR	76	53
MAY	84	60
JUN	94	70
JUL	93	71
AUG	92	69
SEP	88	64
OCT	78	54
NOV	64	40
DEC	56	35
Annual Mean	74.9	52.0
Absolute	106	4

The effect of increasing the rate of climb and time to climb is shown in Figure 5.3. Based on an initial thrust/weight = 1.10 ratio and an initial altitude of 4000 feet, the vehicle can attain a final altitude of 8000 feet above S.L. in $2\frac{1}{2}$ minutes.

A preliminary estimate of the fuel required to support a 10,800 pound vehicle is shown in the sketch below. This figure simply shows the effect of SFC (or I_s) of various types of engines. However, in order to make a fair comparison of various engines the weight of the entire levitiation system must be considered in addition to the fuel weight.



An initial survey of about 30 different turbojets was made from which the most attractive engines were selected for further study. The engines selected provide the lightest system weight for 1, 2, 4, 5, and 6 engine versions, capable of providing the thrust required. System weight versus running time for these engines is shown in figure 5.4.

The levitation system weight for the initial investigation included:

Engine dry weight
Levitation fuel including 5% service allowance
Fuel system = 4% of levitation fuel
Engine installation and thrust vectoring = 4.5% of installed engine thrust

The fuel weight is based on an initial vehicle weight of 10,800 pounds and conservatively assumes a constant thrust to weight ratio = 1.10.

Also shown on the figure is the weight of a rocket levitation system. Thrust of the rocket levitation system supports 5/6 of the vehicle average weight since the remainder of the thrust (and fuel weight) is provided by the descent engine. A specific impulse of 206 seconds was used as representative of the maximum attainable with rocket propellants applicable to this mission.

The figure shows that the weight of the rocket levitation system is prohibitive for a 5-minute mission. Thus, if a rocket levitation system were selected the mission time would have to be curtailed considerably.

Figure 5.5 shows the thrust available for these selected engines. The ground rules used to obtain the installed thrust available are:

Altitude = 5,000 feet
Temperature = Standard Day plus 30°F
Inlet Pressure recovery = .992
Shaft Horsepower extracted = 60 HP
Bleed air = 4 lb./sec.

Table 5.2 shows the characteristics of these engines and summarizes the jet levitation system weight based on a 5-minute mission.

5.3.2 Jet Levitation Systems

The preliminary configuration study determined that only 2, 4, and 6 engine versions met the design criteria. The BS 59/7, CF700-2B, and the SJ 132 engines were selected for further study as representative of the best engines available in the time period required.

TABLE 5-3

SUMMARY OF SELECTED LEVITATION ENGINES

Sea-Level, Standard Day Performance

Engine Manufacturer No. Required	BS 59/7 Bristol-Siddeley 2	CF 700-2B General Electric 4	SJ 132 General Electric 6
Take-Off Rating			
Thrust-lb.	8000	4200	3050
SFC - lb./hr./lb.	.675	.686	1.00
Time-Minutes	10	5	2
Maximum Continuous Rating			
Thrust - lb.	--	4048	2800
SFC - lb./hr./lb.	--	.684	.98
Engine Weight - lb.	550	615	305
Air Flow - lb./sec.	220	124	43.2
Max. Bleed Air - lb./sec.	14.7	2.54	4.32
Status	In Development	Available	Available

TABLE 5.2

LEVITATION SYSTEM WEIGHT

Engine	BS 53/5	BS 59/7	CF 700-2B	RB 162	SJ 132	SJ 132	JT 12A-6	RB 108
No. Required	1	2	4	4	5	6	6	6
Manufacturer	Bristol-Siddeley	Bristol-Siddeley	General Electric	Rolls-Royce	General Electric	General Electric	Pratt & Whitney	Rolls Royce
Thrust/Eng. @ S.L. Std. Day	18400	8000	4200	4400	3050	3050	2000	2430
SFC @ S.L. Std. Day	.69	.675	.67	1.3	1.00	1.00	.96	1.0
Engine Dry Weight	2550	550	615	267	305	305	436	350
System Wt. with Zero Fuel	3170	1820	3234	1851	2157	2594	3428	2757
System Wt. with 5 Min. Fuel	3950	2530	3939	3182	3190	3627	4417	3790

Table 5.3 shows the pertinent properties of these three engines. Upon further studies the 2 engine BS 59/7 configuration was eliminated because of no engine-out capability and lack of ability to compensate for center-of-gravity shift. Detailed configuration studies were made on three specific jet levitation systems:

SJ132 Horizontal installation (6 engines)
SJ132 Vertical Installation (6 engines)
CF 700-2B Vertical Installation (4 engines)

Table 5.4 shows the levitation system weight for these three configurations. This table takes into account the differences in installation characteristics and thrust losses.

TABLE 5.4

Final Levitation System Weight

Engine Installation	6-SJ132 Horizontal	6-SJ 132 Vertical	4-CF700-2B Vertical
Dry Weight	1830	1830	2460
Installation Weight including thrust deflection system	692	588	708
Fuel System	120	140	111
Jet Fuel	1045	1023	704
Total	3687	3681	3983

Figure 5.6 presents the thrust available for each of these systems. The ground rules used are:

Altitude = 4000 feet
Temperature = Standard plus 30°F
Inlet Pressure Recovery = .992
Tailpipe Turning Loss = 2.5% thrust
Tailpipe Vane Loss = 3.5% thrust
Bleed Air = 8 lb/sec (maximum capacity of CF 700-2B)

Superimposed on this figure is the thrust required based on an excess of 1.10 of the individual T.O.G.W. As can be seen, the performance of the CF700 version is marginal. This is mainly due to the large effect of bleed air on installed thrust for this engine. It must be pointed out that the engines need only be capable of producing the 1.10 thrust for one minute during the initial climb to hover altitude. For the remainder of the mission the thrust required will be equal to vehicle weight or less (5/6 W), allowing the engine to run at below maximum continuous rating.

Because the training vehicle is capable of rapid angular accelerations, the gyroscopic effects of the rotating engine components can induce large angular moments. Figure 5.5 shows the gyroscopic moment vs. vehicle angular rate for the three "finalists." The CF700 engine has the lowest moment because the engine components are contra-rotating resulting in a very small net polar moment of inertia. One method of eliminating gyroscopic effects is to gimbal the levitation engines to always maintain the spin vector in a vertical position. Gimballed engines present a complex engine installation problem in requiring heavy engine mounts, large actuators and flexible ducting.

A simpler method to eliminate gyroscopic effects consists of installing the engines to produce opposing spin vectors. This approach is used in the horizontal version of the SJ 132 configuration and completely eliminates gyroscopic moments.

The fundamental requirement of the levitation system is to counteract 5/6 of the vehicle weight. Hence, the thrust vector must remain vertical regardless of vehicle attitude. In addition, the levitation system must cancel the horizontal drag forces experienced by the vehicle. Hence, the need for thrust vectoring is fundamental. For purposes of this study, thrust vector requirements of $\pm 30^\circ$ in pitch and $\pm 15^\circ$ in yaw were selected. A desired, but not absolutely essential, requirement maintains the thrust vector pivot point in the plane of the vehicle c.g. (minor deviations will exist in all practical situations).

There are a number of methods that will provide two-axis thrust vectoring. The selection of a particular system must consider the trade-off between:

Turning efficiency
Mechanical complexity
Weight and actuation forces
Interference with LEM structure.

Table 5.5 shows a number of vectoring methods. For vertical installation, a two-axis gimballed engine is the most straightforward method, but suffers from excessive system weight due to the large moving mass involved. This can be alleviated by using a fixed engine and deflecting only the tailpipe exhaust by means of ball joints, internal vanes, external flaps, etc.

Horizontal engine installation possesses the same problems as vertical ones and in addition require a 90 degree bend. The loss in bends can be kept small if the average velocity is relatively low and the flow is accelerated in the turn to eliminate separation problems. A preliminary estimate indicates a thrust loss of 2.5% for a 90 degree bend and an additional loss of 3.5% for a set of exit vanes.

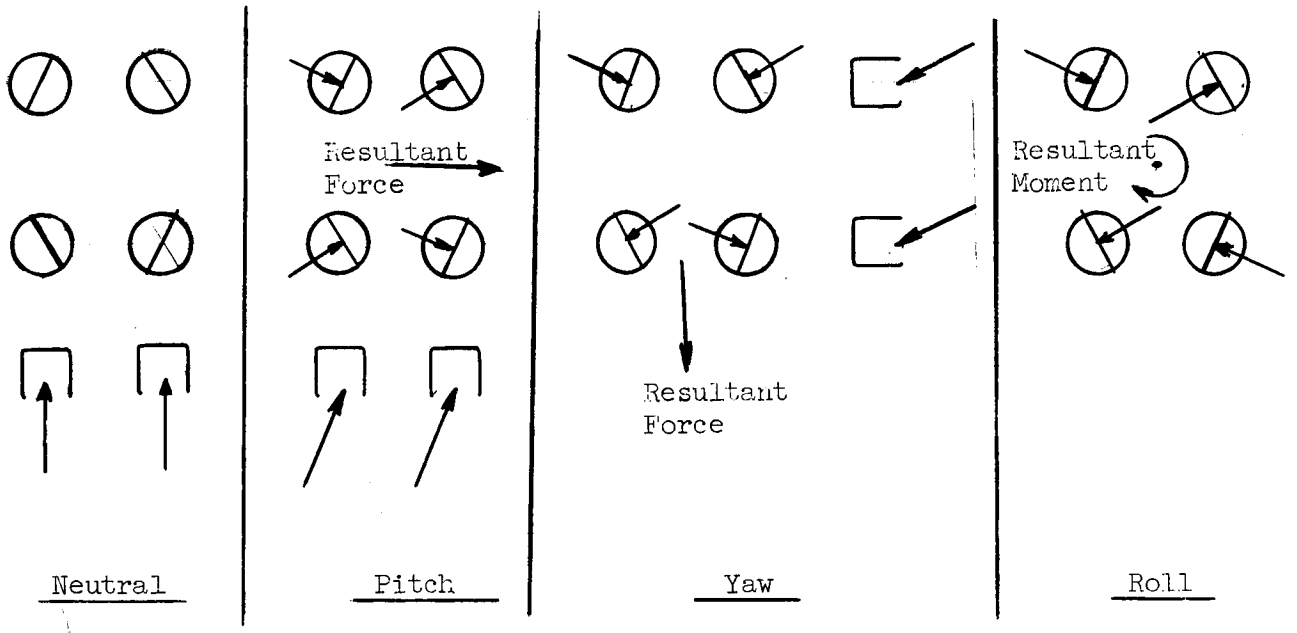
While a conventional vectoring system requires two separate actuators and deflectors to provide pitch and/or yaw, it is possible to perform both functions with a single actuator per nozzle. This system involves placing the thrust deflection vanes at a skew axis with respect to the vehicle orthogonal system. The Skew Axis Vectoring System (SAVES) provides the same net result of vectoring thrust about two perpendicular axis with a single axis of rotation. Vehicle pitch and/or yaw compensation is obtained by differential thrust deflection as shown in the sketch on page 5-10.

TABLE 5.5

TWO-AXIS THRUST VECTORING SCHEMES

Description	Pitch Axis Deflection ±30°	Yaw Axis Deflection ±15°	Comments
1-Vertical Installation			
a) Two-Axis Gimballed Engine	Gimbal #1	Gimbal #1	Neat (no c.g. shift) but heavy
b) One-Axis Gimballed Engine	Gimbal	Internal Vanes	
c) External Flaps	First set rotates	2nd set rotates	Concept may not work for large angles
d) Ball Joint	First joint rotates	2nd joint rotates	Heavy
e) Skew Axis Deflection	Differential thrust	Differential thrust	Light and simple, requires additional thrust
2-Horizontal Installation			
a) Movable Elbow	Elbow rotates	Internal Vanes	Exit vanes, cause high losses
b) Movable Elbow	Elbow rotates	External Flaps	
c) Movable Elbow	Elbow rotates	Elbow Pivots	Heavy, large actuation forces
d) Double Elbow	First elbow rotates	Second elbow rotates	Heavy, severe engine gyro. couple (fore and aft inst.)
e) Ball Joint and Elbow	First joint rotates	Second joint rotates	Very heavy
f) Skew Elbow	Differential elbow rotation	Differential elbow rotation	Light and efficient

Grumman LEM



The advantage of SAVES is the complete elimination of an entire set of rotation schemes and their associated actuation system. Also, as in a gimballed installation, the thrust vector pivot point in pitch and yaw coincide. This concept is applicable to any configuration having two or more engines per side.

The performance penalty for SAVES consists of an increase in thrust and vane deflection required. The skew angle, optimized to provide equal increased thrust requirements in pitch and yaw with LTA-9 angles (±30° pitch and ±15° yaw) is 35.8 degrees off the Y-axis. The maximum thrust to lift ratio to obtain 30° pitch or 15° yaw is 1.062.

A number of thrust vectoring methods have been developed for current prototype aircraft. Unfortunately most of these systems vector thrust only about one axis. The Bell X-14 and the Hawker P. 1127 utilize a combination of a rotating elbow and fixed exit vanes to deflect the thrust vector 90 degrees. The Ryan X-13 and the Short SC.1 gimbal the entire engine through a limited range. Early versions of the Grumman A2F use a ball joint nozzle to deflect the thrust vector 23 degrees for STOL performance. The French Coleopter used external vanes to provide small thrust deflections about two axis. Hence, it is concluded that thrust vectoring is present day state-of-the-art and should offer no difficulties in this program .

An engine-out capability comparison was made to determine the thrust available after failure of one levitation engine. In the event of a failure, the opposite engine is automatically shut down to maintain equilibrium and the remaining engines are brought to their maximum rating. Discussion with the engine manufacturers indicates that the SJ-132 engine can be operated at 110% of take-off thrust for a limited period (one minute).

Under these circumstances the SJ-132 versions are just short (by a few hundred pounds) of providing sufficient thrust with the present mission ground rules and vehicle weight. If the bleed air system is shut off during an engine failure, the thrust of the SJ 132 versions is sufficient to make a safe descent. As can be seen from Table 5.6, the thrust of the 4 engine (CF 700) configuration must be supplemented by the descent rocket engine. Any two-engine version is incapable of engine-out operation since both engines must be shut down for equilibrium.

TABLE 5.6

ENGINE OUT CAPABILITY			
Engine	(6)SJ-132 Horizontal	(6)SJ-132 Vertical	(4) CF700-2B Vertical
Max thrust with one engine failed opposite engine shutdown and bleed air system turned off (Thrust = 110% T.O. rating)	10,100	10,350	6980
Vehicle weight at end of ascent phase	10,055	9,929	10,669

Since it is very undesirable to shut-off the bleed air system during an engine failure, other methods of providing the slight additional thrust are mentioned. One possibility is to divert all the bleed air into the downward-pointing nozzles. Another means would be to employ an auxiliary JATO system. The most straightforward approach is to reduce the vehicle weight by about 500 pounds. The marginal performance described above applies to a "tropical day" at WSMR altitude. On a standard day at WSMR, the SJ 132 configuration is fully capable of supporting the vehicle during engine failure.

The engine-out capability discussed above is based on the maximum LTA-9 weight during an actual rocket-powered training mission. For most of the flight test period and many of the actual training flights, the descent rocket engine will not be exercised hence eliminating about 1700 pounds of rocket propellant weight. Under these circumstances the SJ-132 configuration provides ample engine-out capability whereas an engine failure of the CF 700 system will result in loss of the vehicle since the two remaining engines alone would still not be capable of supporting the reduced vehicle weight.

A possible problem area with the multiple jet engines is matching the thrust in both magnitude and direction. Several possible solutions exist to matching the thrust. One means is to restrain the vehicle and run up a pair of engines at one time and adjust them until there is no net unbalancing moment about any vehicle axis. This procedure is repeated with all the remaining pairs of engines. Another method of balancing the thrust vectors is to install a system of strain gages or load cells on the engine support structure. The output of these gages is then compared either manually or automatically by the EEC electronic system and the proper corrections applied.

The simplest solution is to ignore the thrust vector unbalance completely and allow the bleed-air trim system to provide the necessary balancing forces. Since the trim system is incorporated for the sole purpose of detecting and compensating all "earth environmental" effects, the engine thrust unbalance does not impose any additional problems.

Figure 5.8 shows the jet levitation system schematic for a typical installation. The system is divided into two separate functional components: Thrust magnitude and thrust direction. Both components are basically controlled through servo actuators by the levitation electronics package with manual override available at all times. In case of an electronic system failure the pilot has complete manual control of the engine throttle. Manual override of the vectoring system consists of locking the nozzles in their center or vertical position since vehicle attitude control can be maintained with the bleed-air trim system during a failure mode.

The only external control to the engine is the fuel control linkage which is actuated by the throttle servo and the pilot throttle quadrant. Fuel is supplied from a common manifold with a shut-off valve to each engine to permit individual starting. A flow meter is inserted in the fuel system to supply fuel-flow information to the weight programmer. A thrust sensor is provided to detect large magnitude thrust changes that are associated with incipient engine failure. When such a failure is detected, the affected engine throttle is automatically closed along with that of the opposite engine to maintain vehicle equilibrium.

Installation arrangements for the various engines and thrust vectoring methods are shown in the Configuration Studies section of this report. Fundamental engine requirements include: a smooth air inflow path to obtain high inlet recovery, an adequate supply of "pure" air to prevent problems associated with re-ingestion of products of combustion, engine cooling provisions, and an exhaust path unhindered by any structural interference.

5.3.3 Rocket Engine Levitation System

A brief investigation was made to determine the performance of a rocket levitation system. In this approach 5/6 of the vehicle weight would be supported by a rocket-powered levitation system that is independent of the LEM descent engine.

The rocket levitation engines for this application must have the following characteristics:

Man-rated

Throttleable (Approximate Range is 3:1)

Gimballeable through large angles (±30°)

Correct thrust level for twin engine operation

Compatible with the LEM propellant systems (propellant type and pressure level)

Gimbal point in horizontal plane through c.g. to avoid pitching moment - attitude coupling.

Table 5.7 is a summary of throttleable engines currently available or in development. Unfortunately, none meet the requirements listed above. To determine the weight of a rocket levitation system, the curve on Figure 5.4 was prepared based on a constant specific impulse of 206 seconds and an initial weight of 10,800 pounds. This impulse value is indicative of the best attainable at maximum thrust and decreases rapidly as propellant is consumed and the engines are throttled. This degradation of specific impulse is shown in Figure 5.9.

TABLE 5.7

SUMMARY OF THROTTLEABLE ROCKET ENGINES (THROTTLEABLE)

Engine	LEM Descent (Mod. for S.L.)	AR-2*	AR-3*	AR-4*	AR-4**	XLR99
Maximum Throttle						
Thrust (sc) lb.	7100	5150	6820	8824	10,001	5,700
I_{sp}	206	203	203	211	222	
Minimum Throttle						
Thrust lb.	1050	2200	1900	1900	2997	-
I_{sp} sec.	106	155	132	135	-	-
Exp. Ratio and	2.3	12	12	12	8	-
Engine Weight lb.	200	225	160	160	160	-
Oxidizer	N_2O_4	H_2O_2	H_2O_2	H_2O_2	H_2O_2	O_2
Fuel	50/50	JP-4	JP-4	JP-4	JP-4	NH_3
O/F ratio	2.0	7.26	7.26	7.26	6.5	
Status	Similar to Descent Engine	Flight rated	Flight rated	Study-growth of AR-3	Study-Growth	Flight Rated X-15

* November 1959 Brochure (Rocketdyne)

** January 1963 Brochure (Rocketdyne)

The disadvantages of a rocket levitation system are many besides the short running time that is available. The large mass change and associated vertical c.g. shift due to the high rate of fuel consumption will detract from a true simulated mission. Rocket thrust gimbal points are not in the plane of the c.g. unless the rockets are mounted up and outboard. Engine life is very short: 8 minutes for

ablative cooling and about 45 minutes for regenerative cooling. If AR engines are used, an additional bipropellant system has to be added to the vehicle.

5.3.4 All Rocket System

One means to reduce the complexity of the vehicle is to eliminate the levitation system altogether and provide the entire lift by the LEM descent engine. This approach does not provide realistic lunar simulation since the vehicle is supported by a one-g thrust vector. Thus, any vehicle pitch or yaw attitude will result in lateral accelerations six times as great as on the moon. Hence, to maintain the same vehicle lateral acceleration, the simulator pitch and yaw angles will be only about one sixth of the values that will be encountered on the moon. Since no separate trim system is contemplated for this scheme, the LEM RCS must provide the additional trim capability to cope with the moments produced by the unbalanced engine thrust vector and aerodynamic moments.

For the basic all-rocket configuration, a modified "battleship" descent engine supplies the entire vehicle lift. Since hovering with an all-rocket engine is very expensive in terms of propellants, a special all-rocket mission profile was defined.

The profile selected is based on that described in Appendix H of "NASA Project Apollo Working Paper 1045." It consists of the following phases:

1) Minimum Thrust/Weight = 1.1
2) Ascent to hover altitude at 20 fps
3) Hover for 30 seconds
4) Descent to an altitude of 15 feet at 10 fps.
5) Touchdown by applying T/W - 1.1 for 3 seconds
6) Reserve 15 seconds hover fuel

Figure 5.10 shows the fuel weight required for this type of mission. Based on a zero-propellant "stripped" weight of 5159 pounds, the fuel required to achieve the 300-foot hover altitude described in the above Working Paper 1045 is 2860 pounds. Thus, with an initial vehicle weight of 8019 pounds and a thrust-to-weight ratio of 1.1, the engine must produce an initial thrust of 8821 pounds.

Since the present engine modified for atmospheric operation is capable of producing only 7100 pounds of thrust, a hover altitude of only 20 feet is provided. This is obviously unacceptable for terminal descent simulation. Figure 5.10 shows also two modifications of the basic mission. If the vehicle is lifted to its hover altitude by some external means, such as a helicopter, and a thrust-to-weight ratio of 1.0 is used (since excess thrust to climb is not required) a hover height of 220 feet can be attained with the present modified Descent engine. If, in addition, the 30 second hover is eliminated, the hover height increases to 500 feet.

In order to increase the hover altitude to 1000 feet with an external lifting source (and T/W = 1.0) requires a thrust of about 10,000 pounds. To achieve the same altitude without external aid the vehicle will require an engine thrust of about 14,300 pounds including the T/W = 1.1 required to climb. To achieve either

of these thrust levels requires considerable modifications of the descent engine as described in section 4.3. In addition to the reduction of expansion ratio required for atmospheric operation, changes to engine thrust geometry are necessary.

Although the basic descent engine parameters such as throttling method, propellants, cooling, and gimballing are retained, the magnitude of the engine modifications described in section 4.3.2 demand practically a complete development program. Based on a maximum thrust of 12,000 pounds the minimum thrust required is about 5000 pounds. The assembly weight of this modified engine is 280 pounds based on a preliminary estimate by Rocketdyne.

In order to eliminate the development of a new engine as described above, an alternate rocket system was considered. This consists of using a cluster of two existing man-rated AR-3 engines in place of the modified LEM Descent engine. While this eliminates the engine development program, the use of AR-type engines dictates a new propellant system that greatly differs from the LEM and hence further reduces the simulation of the propulsion system. Table 5.7 shows that the specific impulse of the AR-3 engine is about the same as that of the modified LEM descent engine: hence, the propellant weight shown in Figure 5.10 also applies for this system.

The AR-3 is one of a family of Rocketdyne liquid propellant rocket engines specifically designed as power plants for aircraft. These engines are regeneratively cooled, offer in-flight throttling and restart capability and have completed flight qualification. The propellants, JP-4 and 90 percent hydrogen peroxide, are fed by an engine mounted turbo pump powered by the decomposition products of hydrogen peroxide. Versions of this engine have been flight tested with an FJ-4 and an F-86F and have exhibited a high degree of reliability.

5.4 BLEED-AIR TRIM SYSTEM

The bleed-air trim system is a reaction control system incorporated in LTA-9 to compensate for moments applied to the vehicle that are not present in the LEM terminal descent maneuver. Items that require this trim system include:

* Aerodynamic moments including engine ram drag
* Misalignment of the levitation thrust vector pivot point with vehicle c.g.
* Shift of vehicle c.g. due to unsymmetrical fuel consumption.

The control power required to overcome the combined unbalancing moments listed above is of the order of 6,000 foot-pounds about the vehicle pitch axis. To overcome this moment requires control power in excess of that available from the engine bleed air unless unreasonable large (30 feet) reaction moment arms are used. (Note: c. g. shift referred to is that of "first cut" conceptual design. This characteristic would be minimized in detailed preliminary design effort).

A major portion of the control power is required to overcome the shift in vehicle c.g. due to fuel consumption. Since this shift is slow, predictable, and practically independent of vehicle attitude, it is possible to eliminate this moment by pre-programming a differential thrust schedule into the levitation engines. With this approach, the control power requirements are reduced to a maximum of about 2,000 foot-pounds which is well within the bleed air flow available.

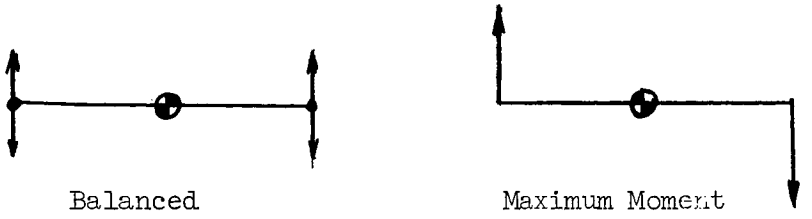
Figure 5.11 shows the bleed air available and the resulting thrust degradation for the more promising 2, 4, and 6 engine configurations considered during the study and also shows reaction nozzle thrust. The CF700-2B (4 engine) version offers the poorest control power capability and also suffers the greatest thrust degradation. For maximum allowable bleed air flow the SJ 132 configuration possesses three times the control power of the CF 700 version.

Although a control torque of about 2000 foot-pounds is sufficient to counteract the normal moments encountered, it is desired to size the actual system to possess the ability to overpower the LEM RCS in the event that the RCS fails in a "hard over" position. Also the size of the trim system must function during an "engine out" condition of the levitation system.

From the above considerations the trim air bleed system was sized based on the maximum permissible airflow extraction of the SJ 132 engines: 21 lb/sec at the hover point. Using a 19 foot moment arm as a minimum value to provide adequate clearance about the yaw axis, a control torque of 3600 pounds is available simultaneously about each of the vehicle's three axis.

Figure 5.12 shows a schematic arrangement of the trim air system. Conceptually, bleed air is extracted from the jet engine compressors and ducted into a control plenum chamber. The purpose of this plenum is to insure uniform bleed air distribution to all trim nozzles regardless of the output variation between individual engines. A check valve is provided between each engine and the plenum to prevent backflow in the event of an engine failure.

Air is then ducted from the plenum to the reaction jets where the flow is controlled by individual nozzles. The trim system consists of twelve nozzles disposed in pairs equidistantly about the three vehicle axes. The sketch below shows the operation of the reaction jets about one axis.



Balanced Maximum Moment

In the neutral position, bleed-air is divided equally to each nozzle thus producing no net force. When a torque is required, flow is diverted to the proper jet by varying the nozzle area through a sliding plug. Since air is always flowing and the control is at the nozzle itself there is a minimum response time lag. Under normal operation, both pairs of nozzles are actuated simultaneously thus producing only a pure couple about the vehicle c.g.

In the event of a nozzle or actuator failure, air to the affected side is shut off by a cutoff valve that controls three pairs of nozzles. Complete attitude control is still maintained about all three axis but a net force is produced when a torque is commanded. This system simplifies the emergency control mode since only two cutoff valves are required for the entire system.

Figure 5.13 shows a preliminary bleed-air system layout based on the 6-engine (SJ-132) configuration. The ducting is sized to efficiently flow the maximum bleed air extraction permissible. Based on the dimensions shown in the figure, a system total pressure recovery of 0.95 was obtained exclusive of nozzle. Pressure recovery of the nozzle is incorporated in the nozzle thrust coefficient of 0.96. These losses are incorporated in the nozzle performance shown in Figure 5.11.

The temperature of the bleed air is low enough (about 470 degrees fahrenheit) to permit use of aluminum alloy ducting. Insulation is provided to prevent overheating some local areas. Figure 5.14 shows the thickness of insulation required to achieve a given surface temperature for two types of insulation.

For purposes of this study, Holley Flow Control valves were selected. This type valve incorporates the control and nozzle section in a single unit. The valve is basically a plug nozzle with a movable metering sleeve. Figure 5.15 is a sketch of Holley model R 415 control valve which combines a pair of complete jets into a single housing thus providing the opposing thrust vectors described above. For the LTA-9 application, both metering sleeves are tied together and actuated by a common input lever. The weight of the entire bleed air trim system as shown in figure 5.13 is 213 pounds.

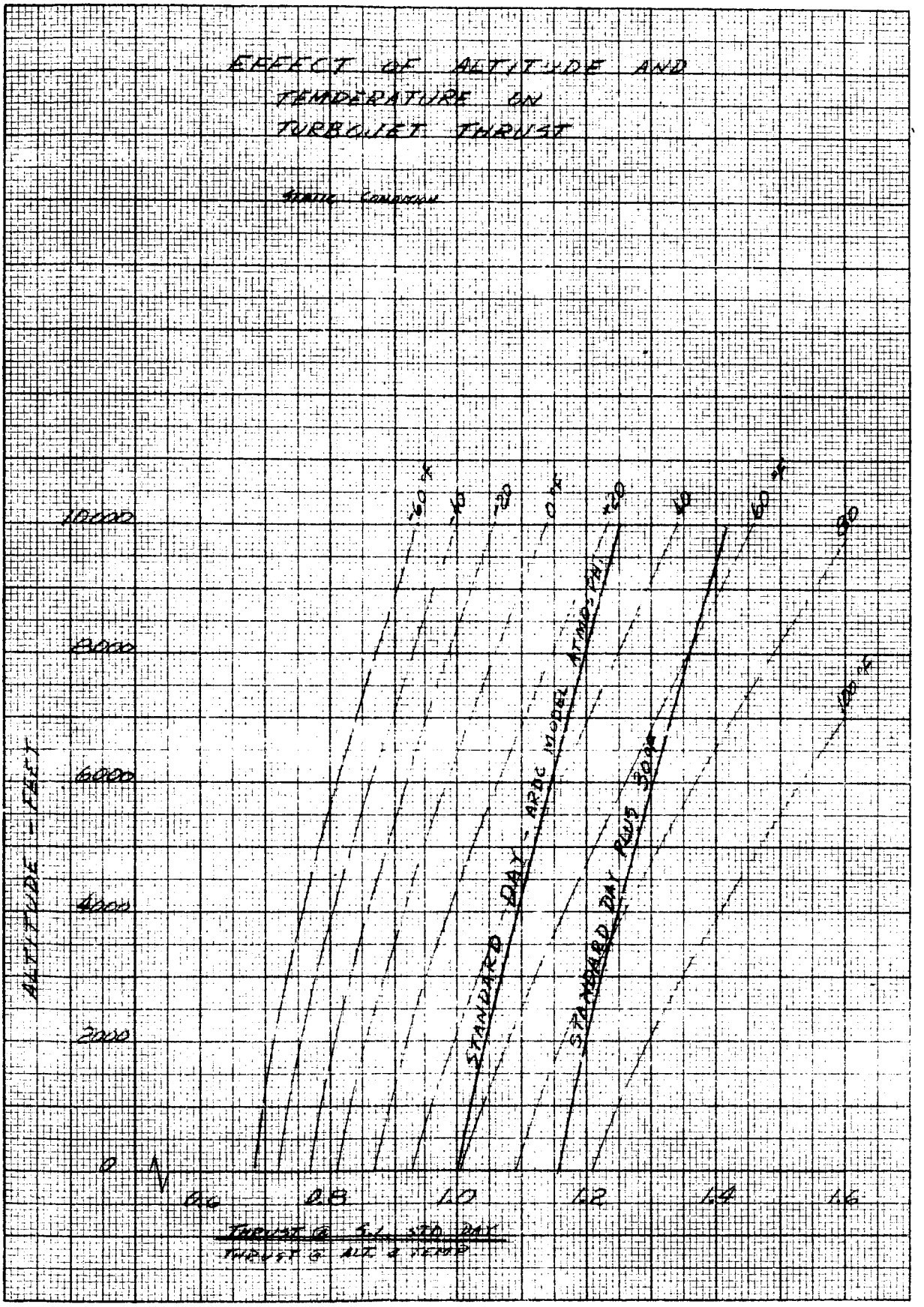
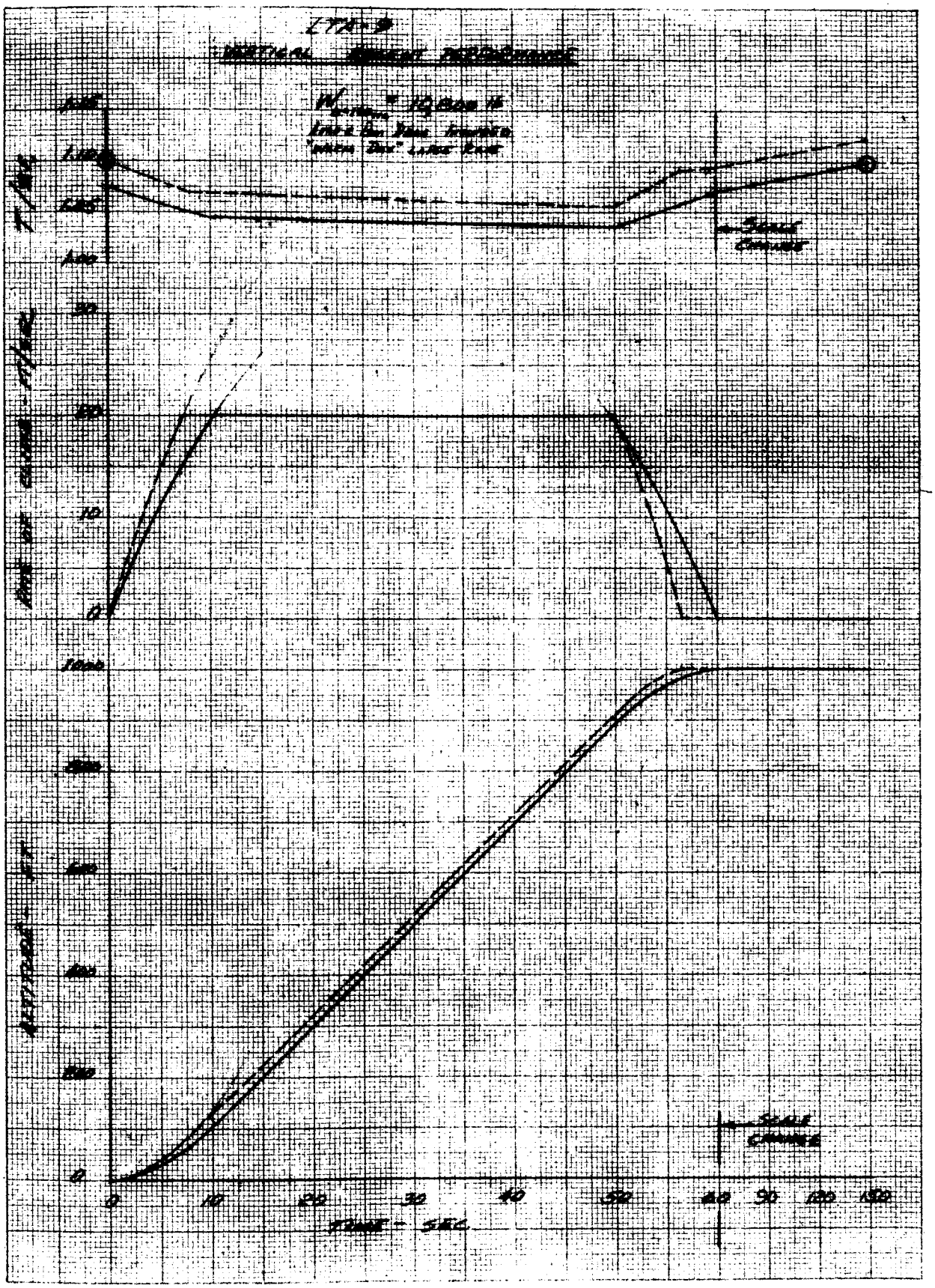


Fig. 5-1

CONFIDENTIAL

Grumman LEM



Grumman LEM

Fig. 5-

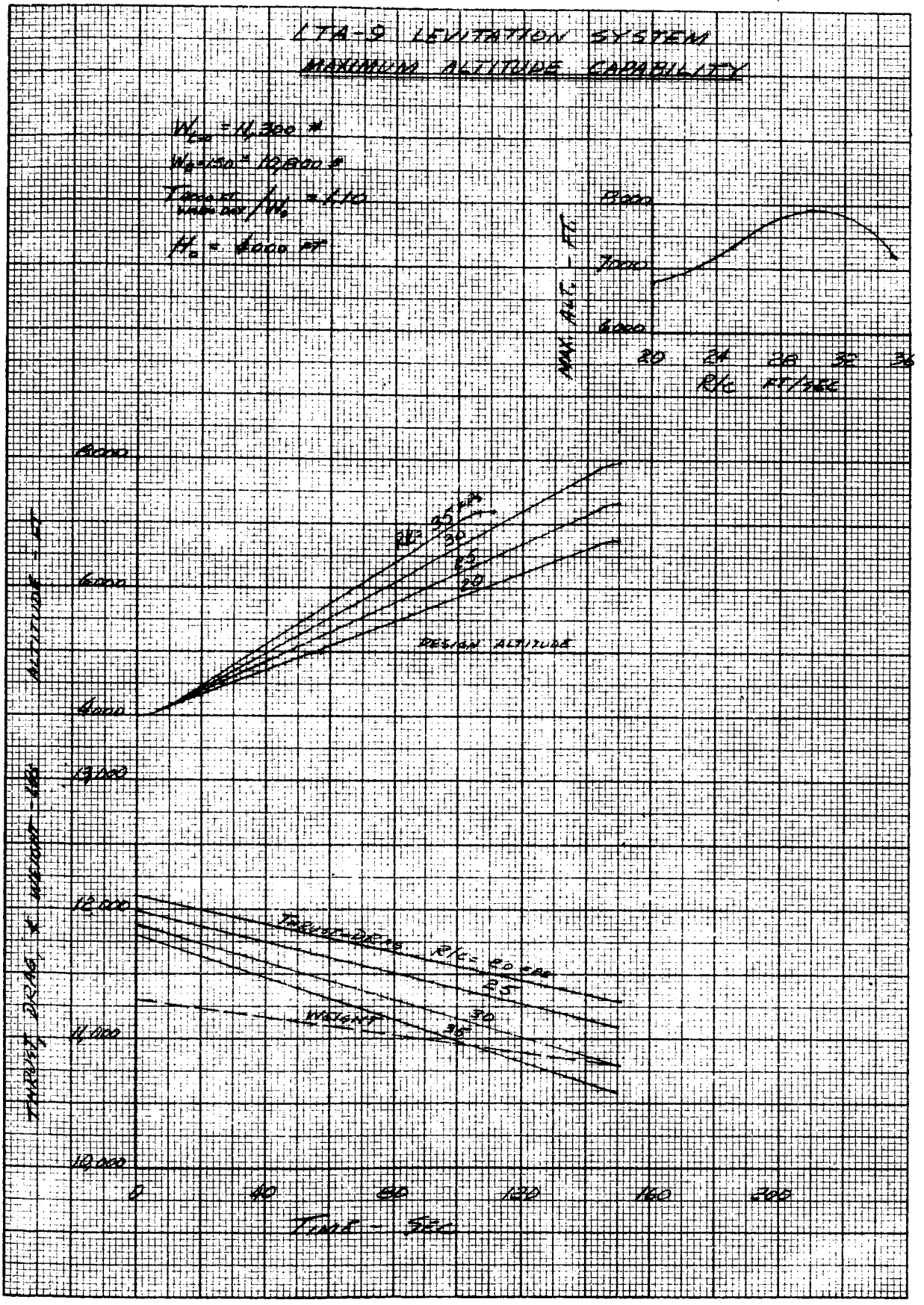

LTA-9 LEVITATION SYSTEM
MAXIMUM ALTITUDE CAPABILITY
W_{LM} = 41,300 #
W_g = 10,800 #
$T_{max\ vac}/W_g$ = 4.10
H_o = 4000 FT
MAX. ALT. - FT.
R/C FT/SEC
DESIGN ALTITUDE
THRUST DIRN. ✕ MISSION ALTITUDE - FT
TIME - SEC

Fig. 5-8

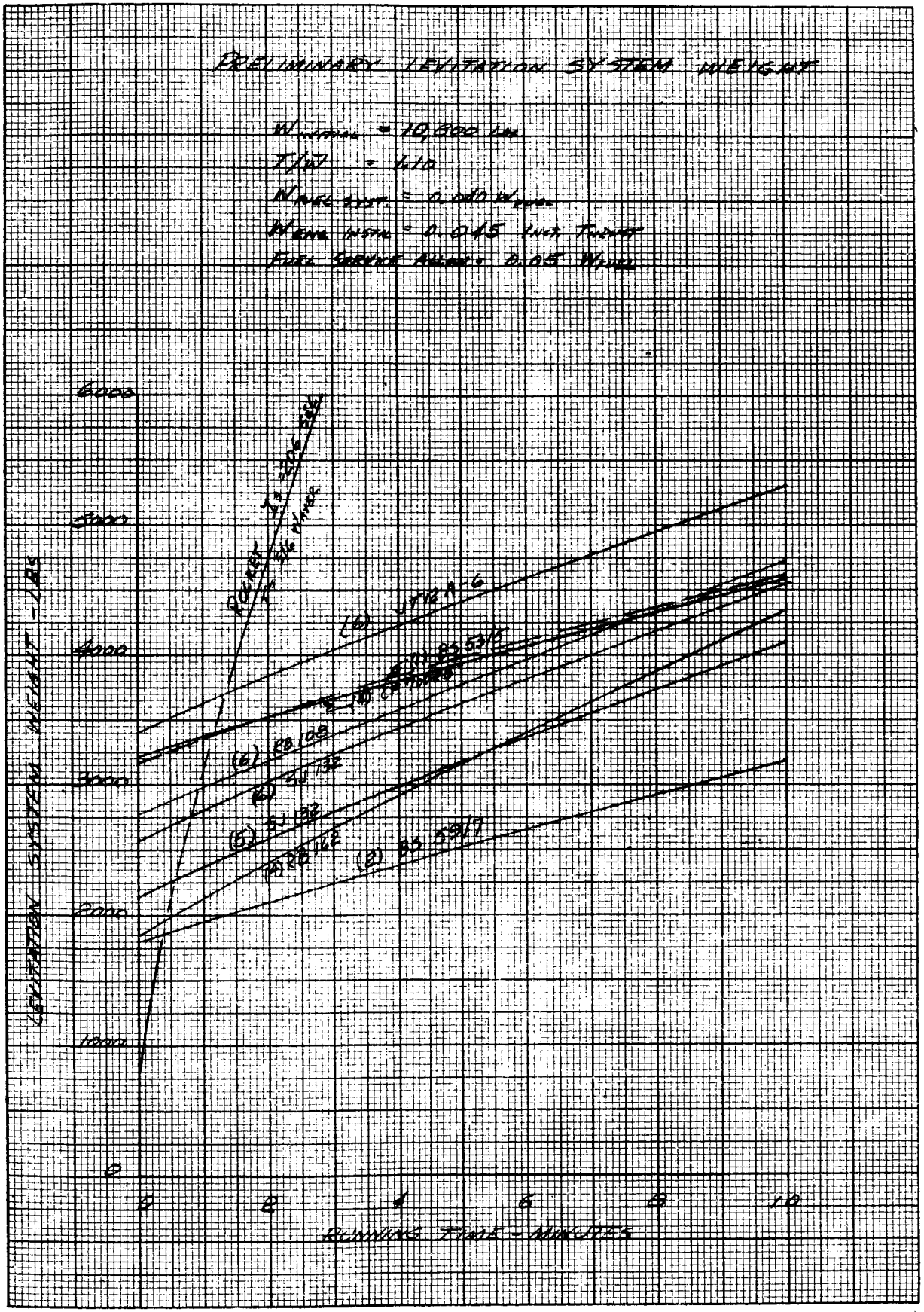


Fig. 5-4

Grumman LEM

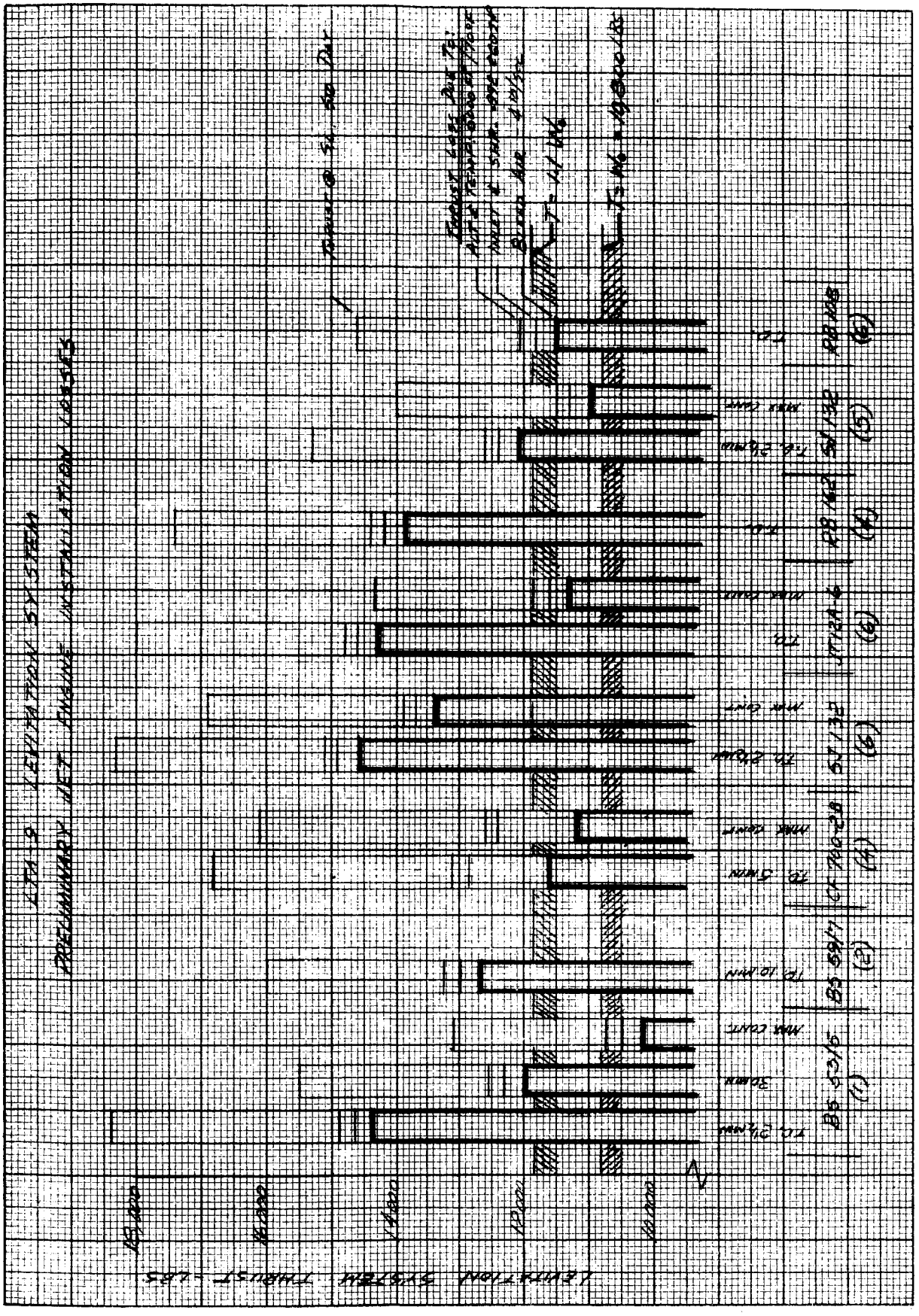
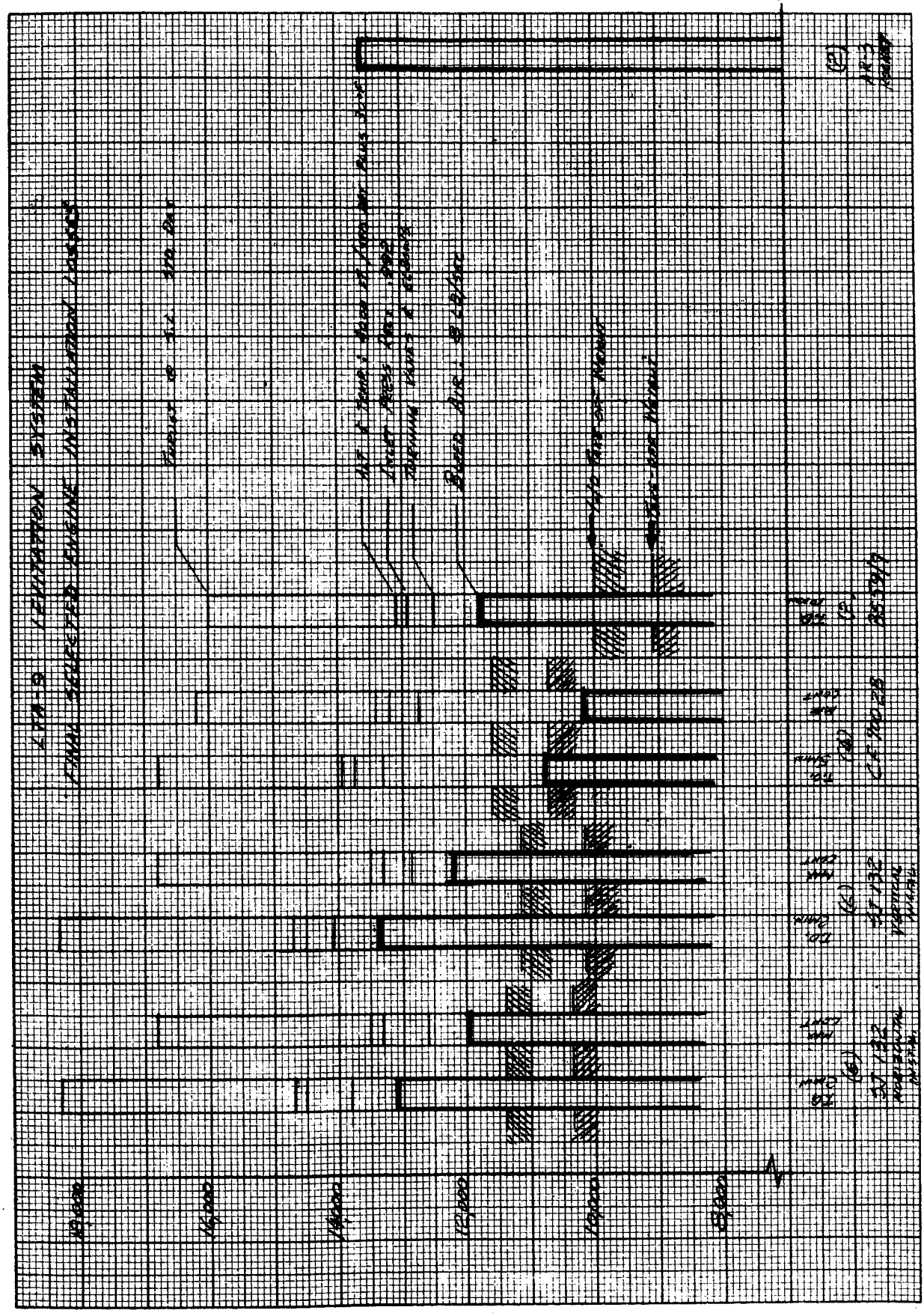
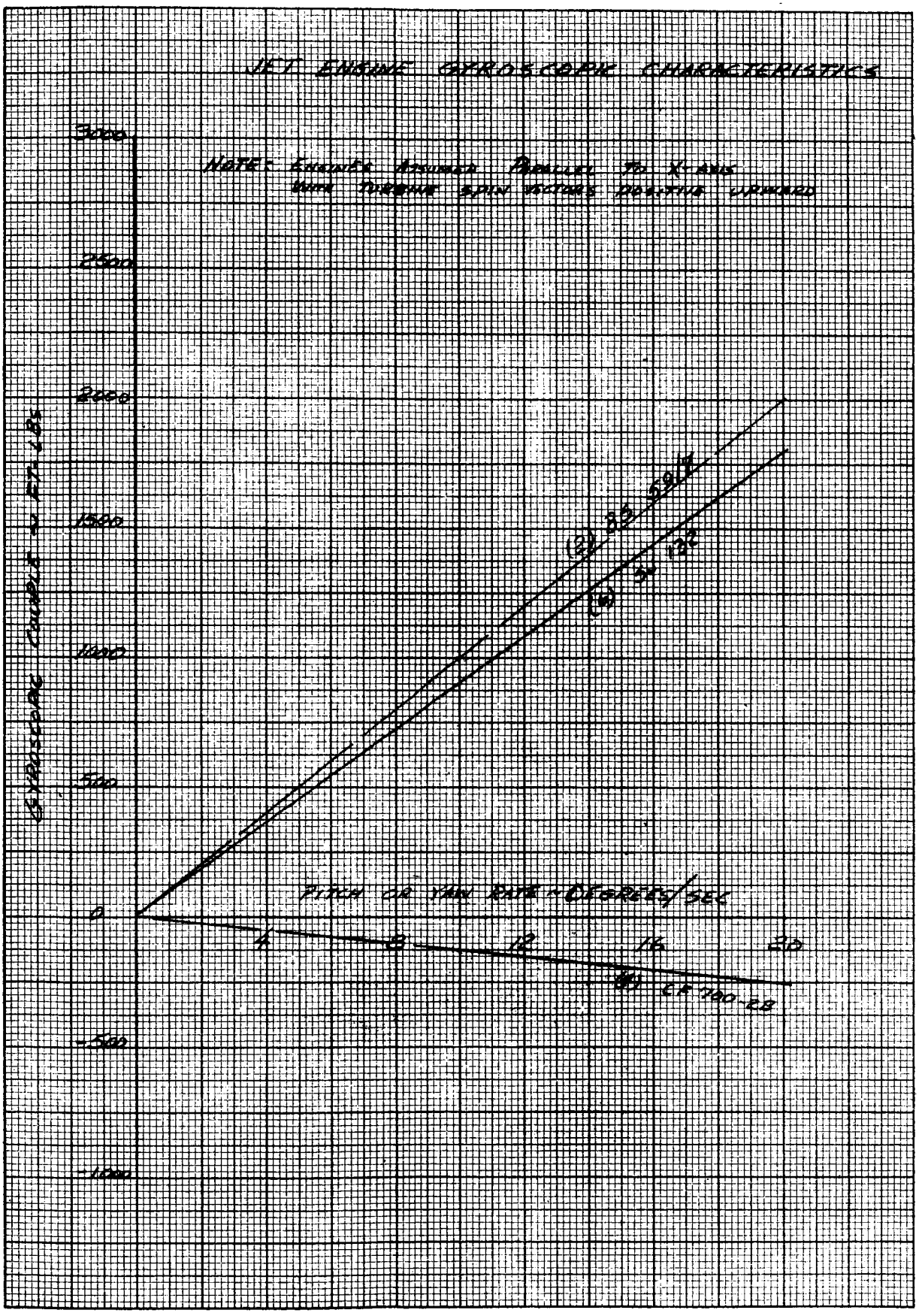


Fig. 5-5



Grumman LEM

Fig.


JET ENGINE GYROSCOPIC CHARACTERISTICS
NOTE: Example assumes Propeller To X-axis
Main Turbine Spin Vectors Positive Upward
3000
2500
2000
1500
1000
500
0
-500
-1000
Gyroscopic Couple, Ft-Lbs
Pitch or Yaw Rate - Degrees/Sec
4
8
12
16
20
(1) CP 100-28
(2)
(3)

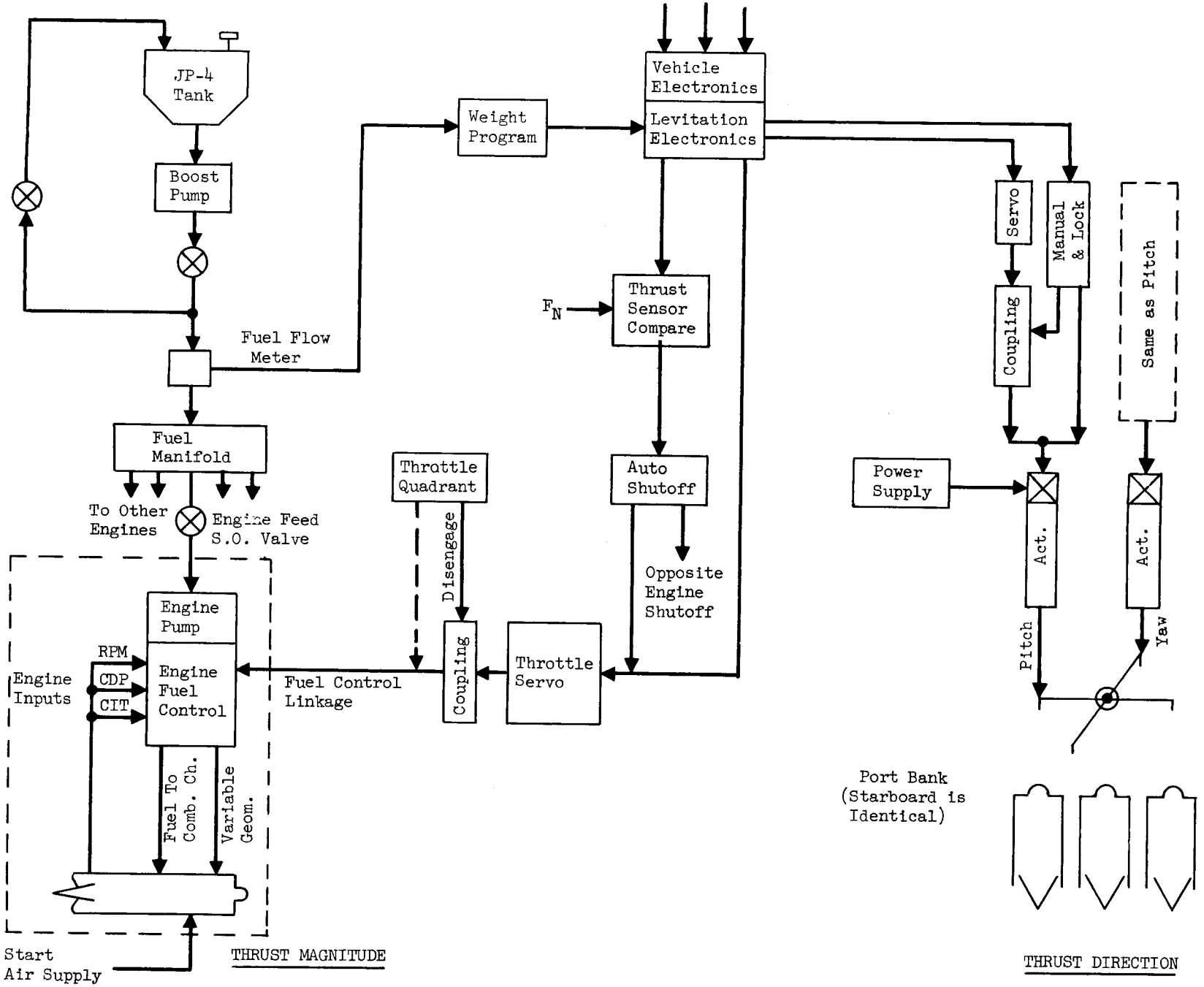
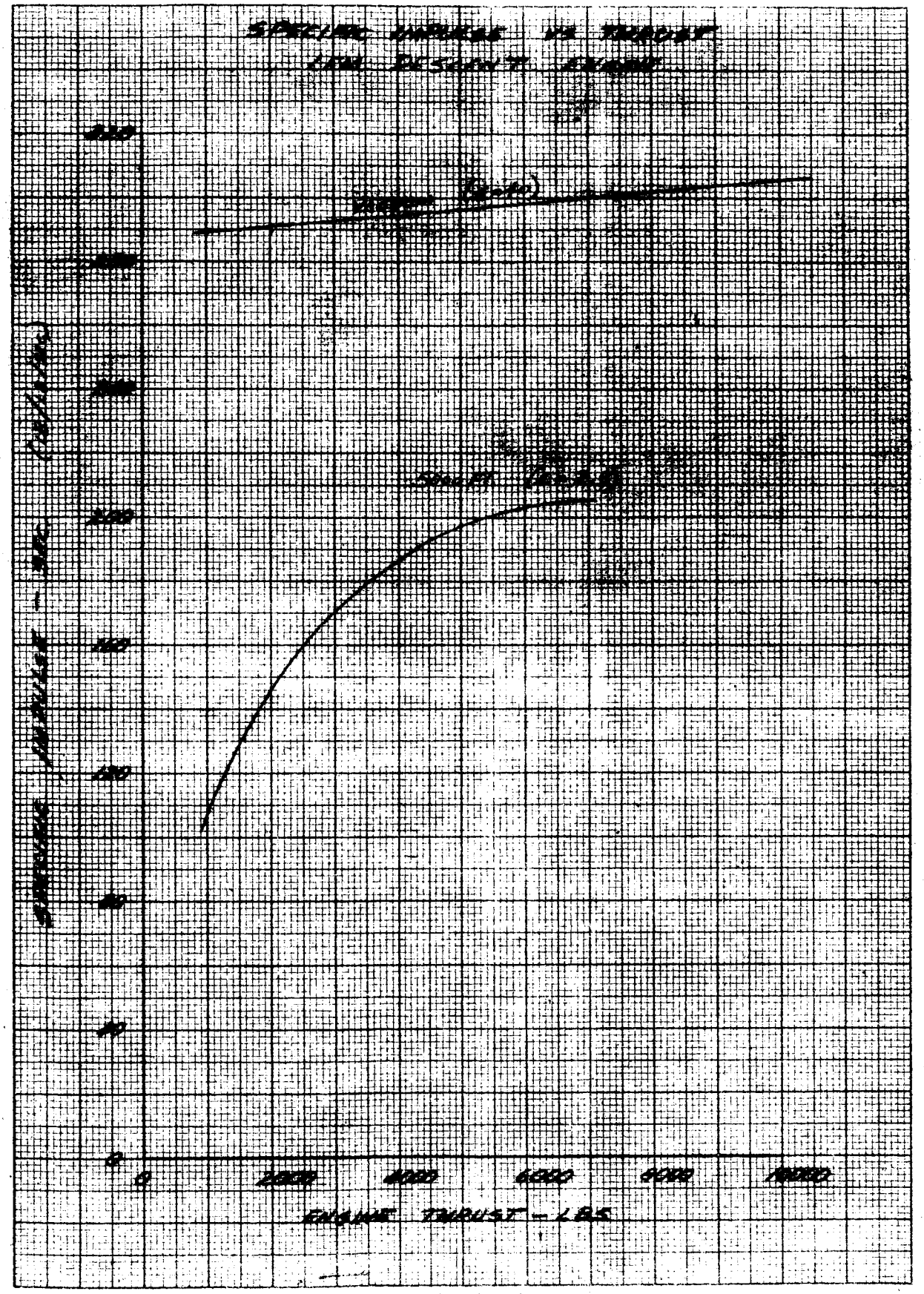


Fig. 5.8 Levitation Engine Control System Schematic



Grumman LEM

Fig.

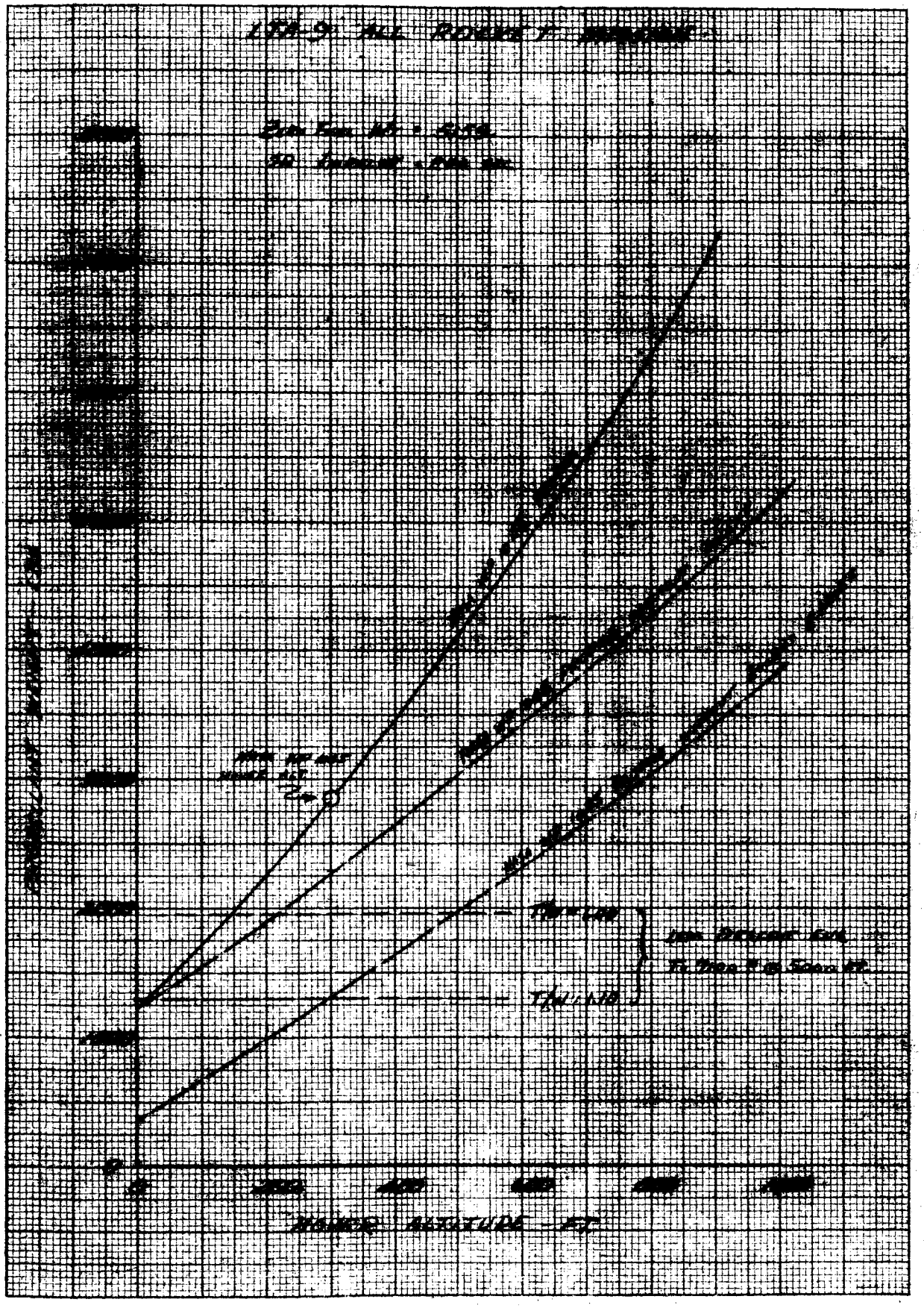


Fig.

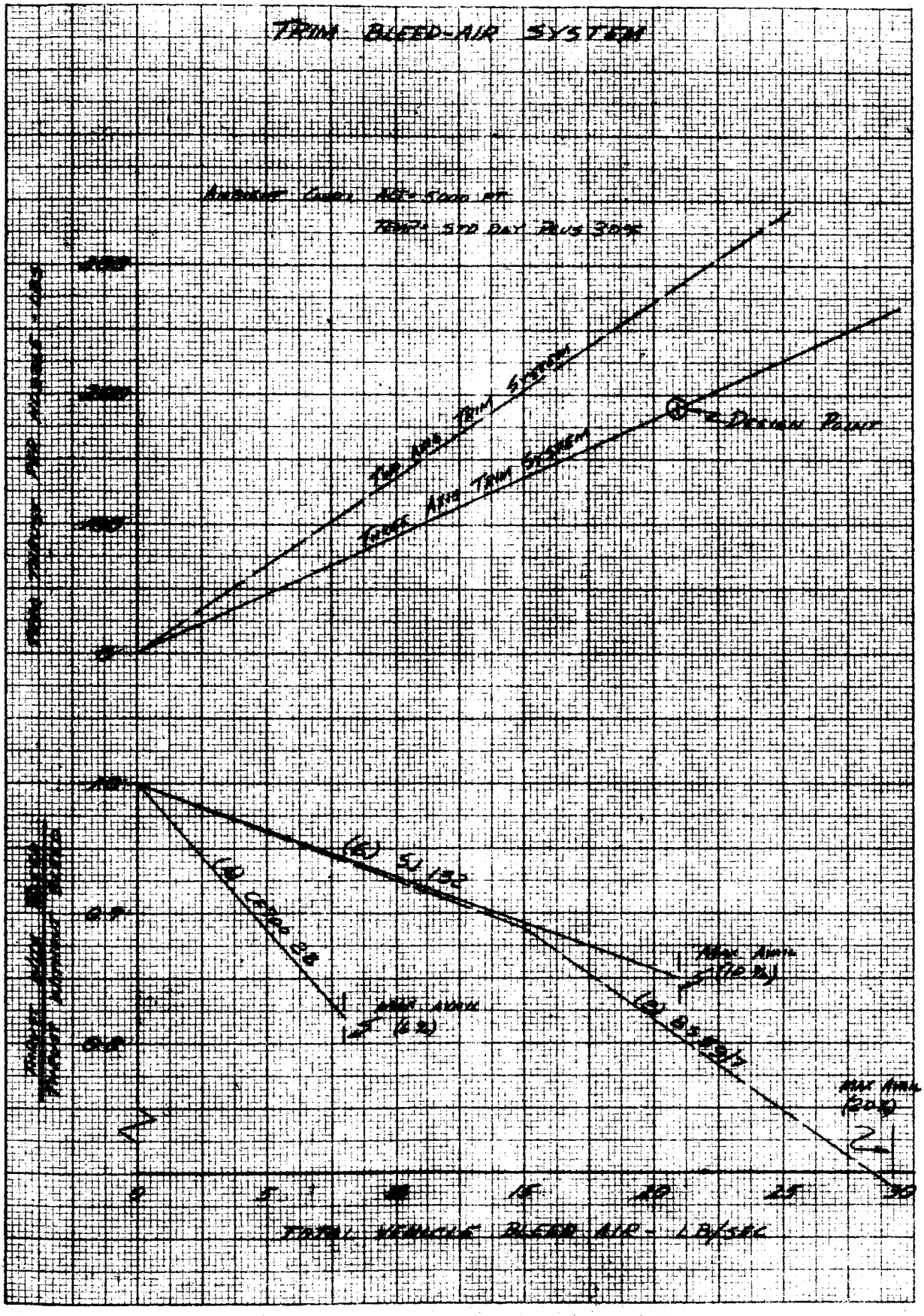

TRIM BLEED-AIR SYSTEM
Ambient Cabin Alt = 5000 ft
Temp = STD DAY Plus 30°F
Trim Bleed Air System
Trim Bleed Air System
Design Point
Max Amb (120 lb/hr)
Max Amb (20 lb/hr)
Max Amb (20 lb/hr)
TOTAL VEHICLE BLEED AIR - LB/SEC

Fig. 3.11

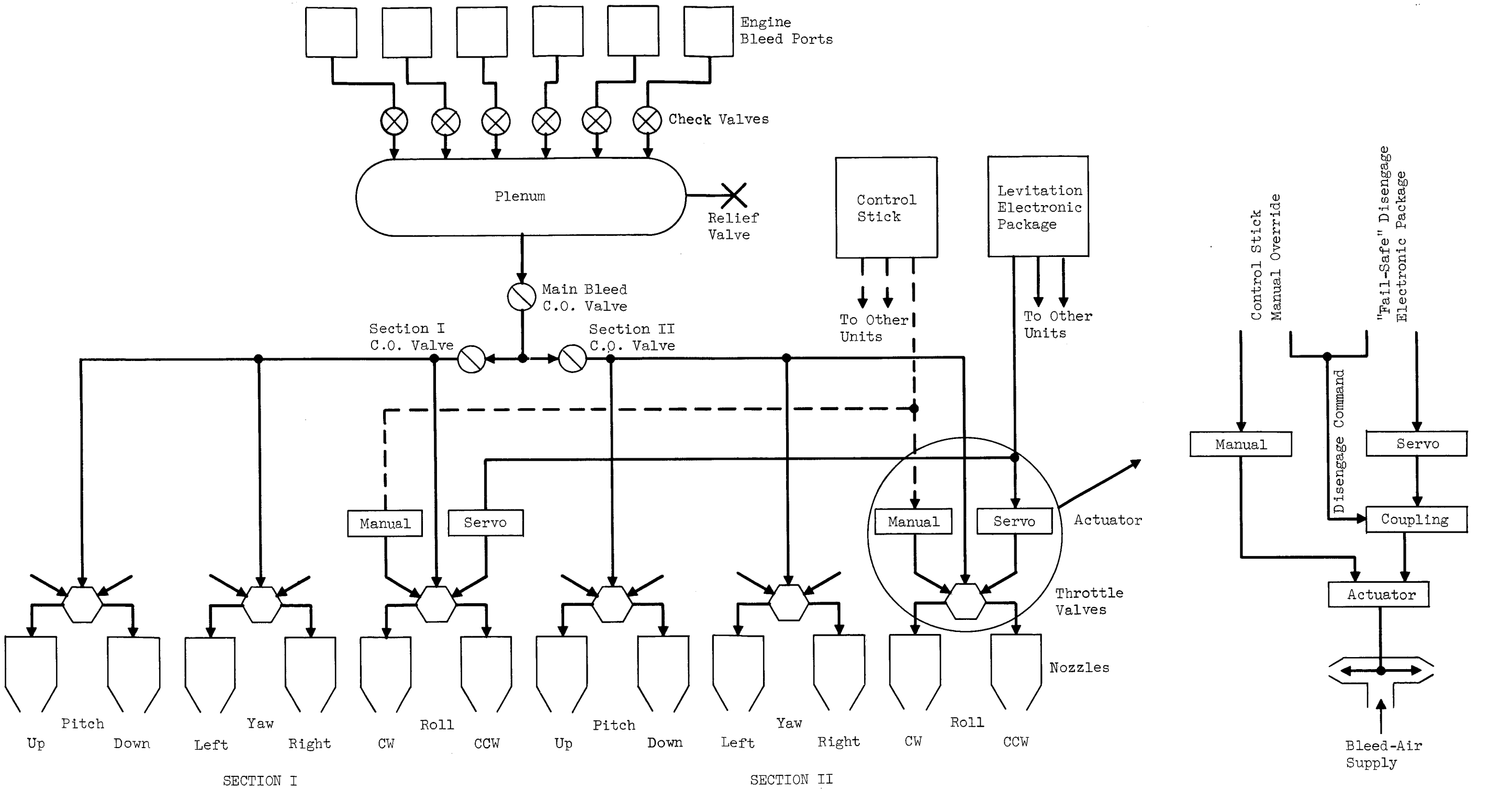


Fig. 5.12 Levitation Reaction System Schematic

LTA-9 BLEED-AIR TRIM SYSTEM

TYPICAL LAYOUT ARRANGEMENT

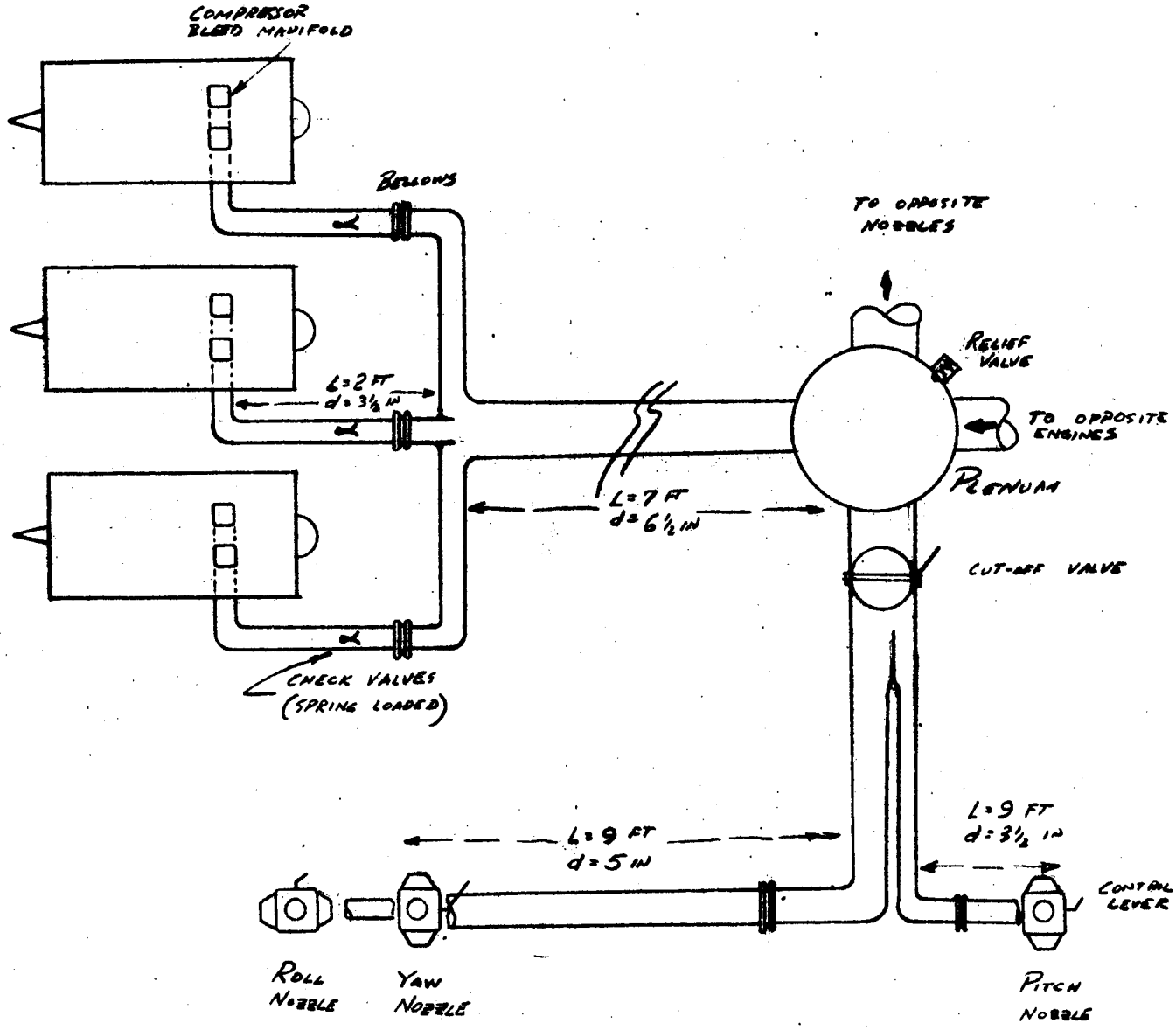


Fig. 5-13

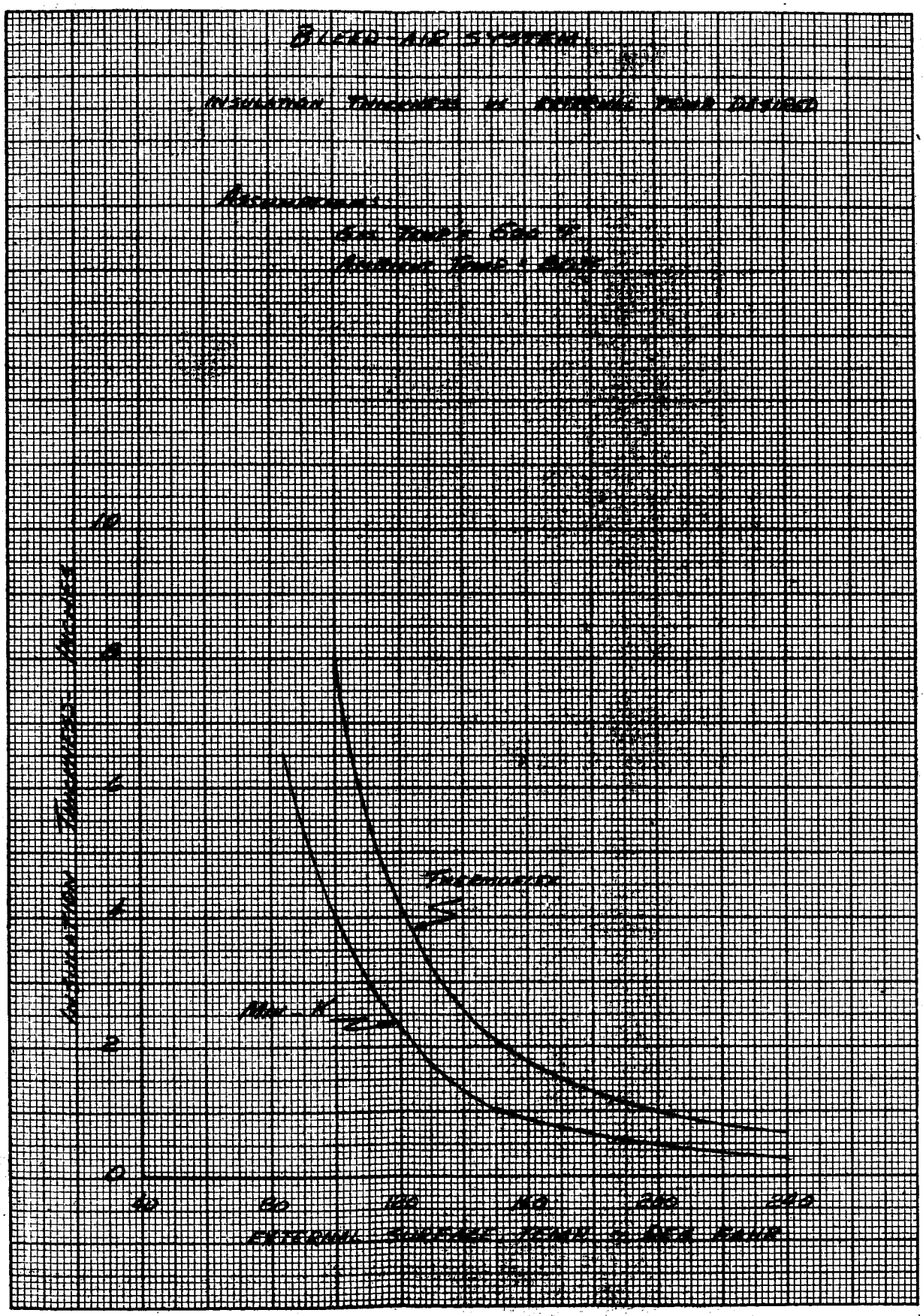
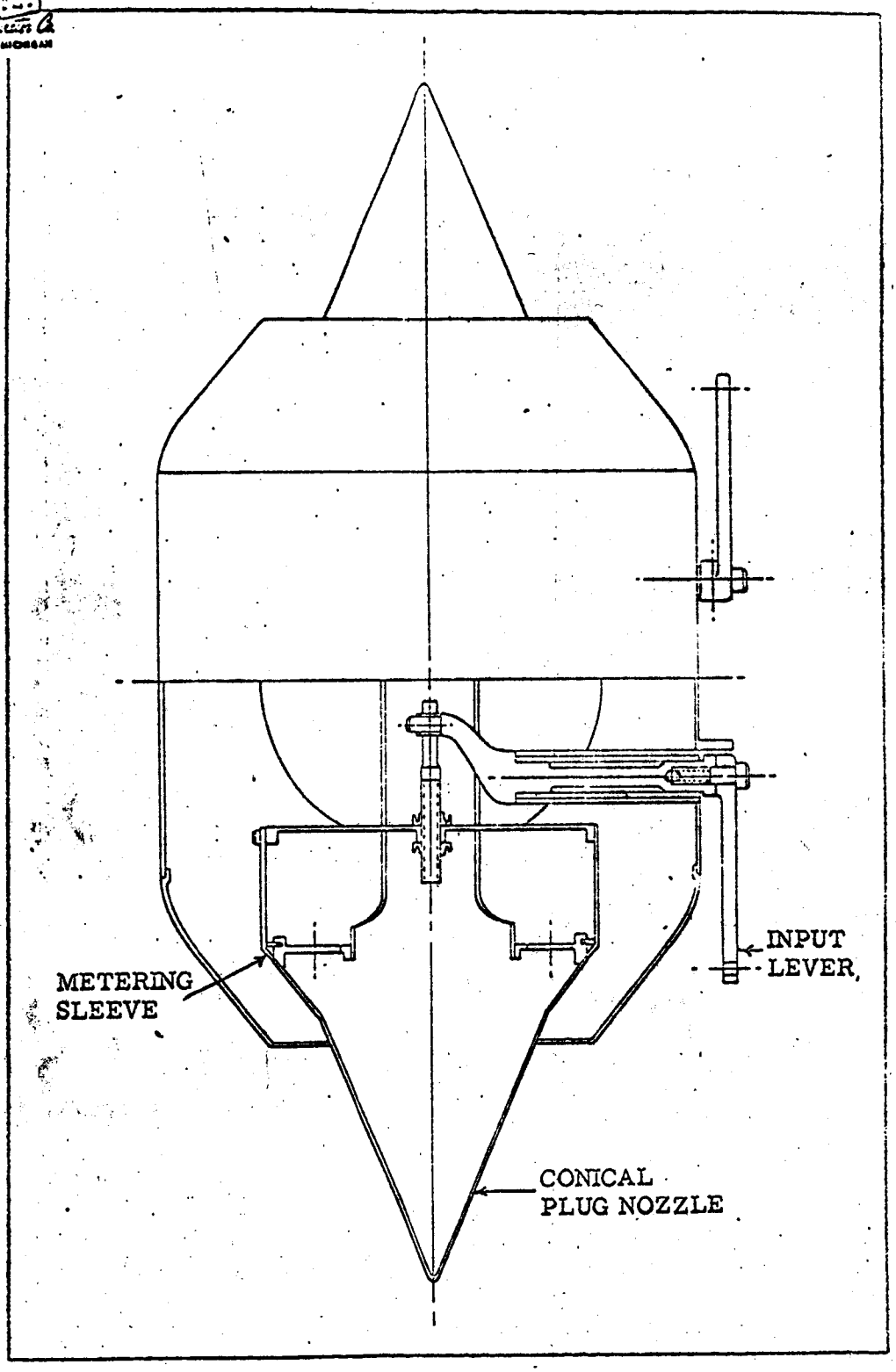

BLEED-AIR SYSTEM
Pressure Decrease as Manifold Tank Is Used
Assumptions:
Manifold Tank Pressure
Thermocouple
Pressure
Time
Extravehicular Suit Circuit Pressure
Extravehicular Suit Circuit Pressure
Time

Fig. 5-14



HOLLEY R415 YAW CONTROL VALVE

Fig. 5.15

5.5 EEC CONTROL SYSTEM

5.5.1 General Operation

The EEC system is relied upon to maintain simulated lunar flight conditions with respect to gravity differences and the cancellation of forces and moments produced as a result of flight operations in the earth's atmosphere. At the same time the system must not introduce any dynamic disturbances through its own functions that will adversely effect its operation.

5.5.1.1 EEC Capability Summary

The EEC system in the automatic mode will enable LTA-9 to exhibit LEM's lunar dynamic characteristics, it is also capable, in the manual mode, of controlling LTA-9 and also overcoming any LEM control subsystem malfunction. The translational velocity and angular rate control capabilities of the LEM are compared to those of the LTA-9 in figures 5-16 and table 5-8. As indicated in this figure LTA-9's manual mode control capability, using the EEC alone, exceeds that of the LEM. The combinations of gain ranges and component time constants that have resulted during the EEC feasibility study (see section 5.5.4 and 5.5.6) are well within the limits of available hardware. The design limits materialized from consideration of two types of terminal descent trajectories: a quarter-cycle sine wave flight path and a helicopter-type flared landing. These trajectories are defined and illustrated in section 5.5.3 and figure 5-19 respectively. The applied loads were based upon the wind tunnel results of section 4. Comparing the range of handling qualities to be simulated (based on the Grumman LEM Proposal) LTA-9 will produce the desired damping and control power levels. Table 5-8 compares the LEM control power with that of LTA-9.

Control power vs. time constant, i.e. Stillwell curves, for the LTA-9 with EEC on both automatic and manual modes show that the handling qualities of the LTA-9 are within the acceptable range. The handling qualities of the LEM are included in figure 5-28 for comparison with LTA-9 characteristics.

Three conceptual flight control systems were evaluated in arriving at the system which offered the best simulation of the mission in conjunction with flight safety and design flexibility.

In regard to design flexibility, if the performance requirements (see figure 5-16) of LTA-9 were reduced, e.g. the maximum velocity reduced from 75 fps to 25 fps, the EEC control system could be simplified since aerodynamic forces and moments are negligible. The shaded blocks appearing in figure 5-18 indicate, schematically, how the EEC subsystem could be simplified by eliminating certain components.

Consideration was also given to an all-rocket LTA-9 configuration. From a control systems viewpoint, although the restricted vehicle performance capabilities result in a control system more like the basic LEM, the vehicle's flying qualities will of necessity be different from the LEM.

5.5.1.2 Overall Control System Approach -
Three conceptual control system configurations were studied. Crew safety, state-of-the-art component performance, and close simulation of LEM lunar performance characteristics were the guidelines in selecting the EEC approach.

Error Sensing - To be fully compensating, EEC system response must be a function of moon-earth differences. Since it is possible to predict the LEM's response to a control input on the moon accurately (basically because of the lack of a lunar "atmosphere"), it is possible to synthesize these error signals with an analog computer model of the moon vehicle. This Lunar Computer is the basic element of the model adaptive control system employed.

Manual pilot commands simultaneously go to both the LEM Stabilization and Contol Subsystem and the Lunar Computer. The output of the Lunar Computer will be the dynamic response that the LEM would experience in the lunar terminal descent. These dynamic responses will be in the form of linear and angular displacements, velocities and accelerations. LTA-9 body axis accelerations and rates will be sensed by the LEM IMU, however a three-axis rate gyro and accelerometer package would also suffice. The difference between lunar and actual body translational and rotational accelerations will be used to drive the compensating system.

Since mass properties affect dynamic responses a mass properties computer will compute both a lunar and the earth vehicle mass property changes. The signals from this unit to the Lunar Computer will be instantaneous mass and inertias.

Conceptual Configurations - The conceptual configurations investigated included:

(1) a fully compensating system,
(2) an open loop system,
(3) a closed loop system with malfunction sensing.

These configurations are shown schematically in figure 5.17.

Fully compensating system - The system uses the Lunar Computer to compare an actual, measured response with a calculated response based on instantaneous mass and control input to define the error. The signal is then used to drive the EEC automatically. This system will automatically compensate for LEM control malfunctions.

If malfunction training is desirable malfunctions should be both selectable and predictable in order to insure flight safety. As indicated in figure 5.17(a) the fully compensating EEC system also lends itself to planned malfunction inputs. Preprogrammed malfunctions can be selected manually. A malfunction generator is an optional system of relays, switches and signal sources used to apply extraneous inputs to the LEM Stabilization and Control, Reaction Control subsystems, and to EEC.

Open Loop System - This system, figure 5.18(b) utilizes air data inputs to compute earth environmental disturbances which in turn drive the EEC power components automatically. This requires sensing vehicle velocity and

computing the aerodynamic forces from preprogramed equations. A signal which is a function of lunar response is then sent to the EEC power section. The system is open loop and its accuracy depends upon the quality of the air data measurements as well as component accuracies. It can be seen that all errors in the air data sensing are integrated in the output signals.

Althought this approach will allow the vehicle to respond to LEM system malfunctions, system complexity and the errors associated with the use of measuring instruments such as anemometers and static sources makes its use undesirable.

Closed Loop System with Malfunction Sensing - Figure 5-18(c) illustrates a system that allows LTA-9 to respond to malfunctions by utilizing the output signals of an in-flight monitor. The inflight monitor senses the malfunction, converts the signal and sends it to the Lunar Computer. The Lunar Computer will respond with an LTA-9 response simulating the LEM malfunction in the lunar environment. An undesirable feature of this approach is that LEM and EEC malfunctions cannot be discriminated. This can result in precarious conditions since no prior knowledge of an imminent malfunction is available.

Selected Approach - The fully compensating control system was selected as the best approach for the LTA-9 mission. The following sections describe the EEC subsystem based on this selected approach.

5.5.2 CONTROL SUBSYSTEM DESCRIPTION

5.5.2.1 Configuration Selection - Vehicle requirements and the applied loads indicate the control system is to perform three basic functions. It must tilt the jet thrust vector in two planes, compensate for lift and drag and stabilize the effects of aerodynamic moments with an auxiliary trim or moment control. The moment control considered here is an engine bleed-air subsystem. The overall 3-channel block diagram is illustrated in figure 5-18. The major operational channels of the system are discussed in section 5.5.6. If more trimming power is required for c.g shifts, differential throttling of the jet engines is a feasible approach when four or more engines are used. However, an LTA-9 design goal would be the duplication of LEM c.g. arrangement during the design phase of an LTA-9 program (shift characteristics) which will be within the trim capability of the auxiliary moment control.

5.5.2.2 System Sizing

The control system is sized by the following considerations:

1. LEM response
2. Disturbances
3. Handling qualities
4. Safety margin

The system performance capabilities are compared to LEM capabilities in table 5-8.

TABLE 5.8

COMPARISON OF MAXIMUM CAPABILITIES OF LEM AND LTA-9 WITH EEC ALONE*

Vehicle	Phase	$\ddot{\theta}$ deg/sec^2	$\ddot{\varphi}$ deg/sec^2	$\dot{\theta}$ deg/sec	$\dot{\varphi}$ deg/sec	$\dot{z}$ ft/sec	$\dot{y}$ ft/sec
LEM	Hover	9.9	9.73	17.25	12.1	4.86	1.73
	Landing	10.8	10.6	18	12.6	4.61	1.65
LTA-9	Hover	36.8	35.3	33.1	23.1	15.3	5.5
	Landing	49.9	38.4	38.7	23.6	13	4.97

* Thrust vector equal to weight of vehicle

5.5.2.3 Functional Control Loops - The basic EEC system must include: jet engine thrust vector magnitude and direction control, and moment control. The system is shown schematically in figure 5.18.

Thrust Vector Control - The thrust vector direction control will be obtained by orienting the thrust vector to a given position with respect to the vehicle body axes. Any vehicle attitude change will be sensed and the jet attitude loop will orient the vector so as to maintain a 5/6 g anti-gravity force on the vehicle. When drag forces act on the vehicle, this vector will be tilted off the local vertical as a function of acceleration response error yielding a component of thrust to cancel the drag. Free gyros will maintain a vertical reference, if the I.M.U. is not available.
A jet throttle command results when a jet attitude change from the local vertical is made so that the 5/6 g vertical component will be maintained. The signal to the throttle is the output of a resolver whose input is a jet attitude change with respect to a local verticle reference.

Jet Throttle Control - The jet throttle control as shown in figure 5.18 will respond to an error in X-axis translational acceleration and a jet engine attitude change. The X-axis translational acceleration is the difference between computed and actual vehicle response. A throttle signal can also originate as a function of jet thrust vector change from a local vertical direction.

At the hover point the jet thrust to rocket thrust ratio will be set at 5:1 with the total equal to the vehicle's instantaneous weight. The system will be set on automatic mode. From this point on, the EEC system will automatically adjust to maintain the vertical component of the jet thrust vector at the proper magnitude as a function of vehicle weight.

Auxiliary Moment Control - Moments due to aerodynamic efforts, jet engine intake air momentum drag, and c.g. shift are counteracted by the bleed-

air reaction control system. At the maximum bleed air capability of the SJ-132 jet engines (10%) the bleed air RCS can exert a control moment of 3600 ft/lbs. per axis. Since LEM has a maximum control power of 1100 foot pounds, the bleed air system can compensate for or override any RCS malfunction.

The auxiliary, (bleed-air) moment system is driven by an error signal proportional to the difference between a commanded (lunar computer) and an actual angular acceleration. (See Figure 5.18) The difference would arise as a consequence of viscous damping or aerodynamic moments. During the LEM attitude hold mode, error compensation is active only outside the dead-zone imposed by the LEM S & C subsystem.

Forward c.g. shift in the "first cut" conceptual designs introduces a nose down pitching moment which exceeds our total bleed air trim capability. Although this situation can be corrected by differential thrusting of the jet engines (±450 pounds per fore and aft engine provides 1800 foot pound per side) it is expected that c.g. travel can be reduced to a negligible amount in the course of a more detailed preliminary design.

5.5.3 Applied Loads

The applied loads can be divided into two general categories: external aerodynamic loads and inherent loads. The external aerodynamics include drag, lift, and moments: the inherent forces include c.g. shift, jet engine ram-air drag, interference flow, ground effects and control element inertial reactions.

5.5.3.1 Applied Load Limits

In order to assess the control power requirements, the wind tunnel data discussed in 4.2 was applied to two landing profiles which encompass the upper and lower limits of applied forces (Fig. 5.19). These forces are summarized in table 5.9. The time histories for these forces are shown in figures 5.20, 5.21, 5.22 and 5.24.

Table 5-9 shows a summary of applied loads and rates of load.

Flight Profile	Moment ft.lb.		Moment Rate ft.lb./sec.		Drag Force	Drag Rate	Lift Force	Lift Force Rate
	C.G.	Aero	C.G.	Aero	#	#/sec.	#	#/sec
Sine Wave	-1750 -5250	+ 151 - 22	450	68	50 0	10	185 0	185
"Helicopter" Type	+ 600 -3280	0 -1200	369	1080	-15 +60	15	+20 +930	175

Table 5-9 Maximum Load Summary

The sine wave trajectory shown in figure 5.19(a) is the result of a landing trajectory study aimed at approximating a minimum ΔV profile. The altitude range profile of the trajectory has the shape of a quarter-cycle sine wave. The guidance law used requires that sink rate and horizontal velocity both approach zero as the altitude approaches zero. After initial velocity and sink rate has been established, subsequent maneuvers are mild and control power requirements are consequently low. This trajectory is therefore used to define the EEC system sensitivity requirement.

The second trajectory Fig. 5.19(b) follows helicopter landing technique in using an initially high rate of descent followed by a flare-out and relatively slow final approach to touchdown. The purpose of this trajectory is to conserve propellant during the initial descent through use of a high sink rate and then afford the astronaut the opportunity to scrutinize terrain carefully during a "low and slow" final approach to touch down.

This trajectory indicates a maneuver that is within astronaut and LEM limitations, but the resultant velocity (74 ft/sec) and the rapid change in "glide" slope at the flare are sufficiently extreme to represent a maximum design goal for LTA-9. The high velocity imposes high aerodynamic and jet ram air forces on the vehicle and the maneuver requirement during the flare requires high limit control power. The maximum applied aerodynamic forces, force rates, moments, and moment rate experienced during this maneuver are summarized in table 5.9. The sum of all moments is plotted in fig. 5.23.

5.5.3.2 Aerodynamic Loads

(a) Normal lift forces can easily be cancelled because of their relatively small size, and large range of axial thrust power available. Figure 5.22(a) shows that the sine wave trajectory applies less than 200 lbs. of force compared with 930 lbs. for the helicopter trajectory.

(b) Drag forces - (figure 5.21) shows that the axial drag forces (along the vehicle Z axis) for either trajectory never exceeds 60#. The small force indicates that the jet thrust vector need be tilted thru only a small incremental angle. The maximum drag and drag rates are summarized in table 5.9.

(c) Aerodynamic Moments - The maximum aerodynamic moment for the sine wave trajectory is 140 ft/lb. compared with that for the helicopter trajectory which is - 1250 ft/lb. The difference is due to the high velocities established in the latter trajectory. These forces are shown in figure 5-22. The maximum moments and moment rates are summarized in table 5-9.

5.5.3.3 Inherent Loads

In general the aerodynamic loads appear to be small compared with the forces inherent in this design.

(a) The air-intake momentum drag is sizable but in order of magnitude never exceeds 10% of the anti-gravity component. The effects of this force can be decreased by reducing the height of the plenum chamber inlet above the center-of-gravity. (See figure 5-24).

(b) Moment due to c.g. - The moment due to c.g. shift is the largest of all loads, exceeding 5000 ft./lb. With judicial weight programming as shown in Section 4, this force can be minimized. While c.g. shift results in negative moment, moment due to momentum drag is generally positive to give a balancing effect. A composite set of curves is shown on figure 5-23 gives the time vs. applied moment history for both trajectories.

5.5.4 EEC Stability Analysis

The feasibility of the LTA-9 vehicle is to a great extent dependent upon the ability of the Earth Environment Compensating subsystem to perform as required. A linearized stability analysis of the major sections of the EEC subsystem, which includes the

* Jet Engine Thrust Control Section
* Jet Engine Throttle Control Section
* Auxiliary Moment Control Section

has been performed and is summarized in this section. The analysis shows that the conceptual EEC design as detailed in section 5.5.6.1 and 5.5.6.2 is stable. Furthermore, the analysis confirms that the desired stability can be attained with good response characteristics.

In order to ascertain the effect of component nonlinearities on system stability, response, and performance, a more complete analog computer program would be implemented as part of a preliminary LTA-9 design.

5.5.4.1 Jet Engine Thrust Vectoring Control System

During the LTA-9-LEM terminal descent the jet engine thrust vector control system is required for 1) automatic rotation of the jet engine thrust vector in LEM pitch and yaw maneuvers such that the vector is always vertical and opposing the earth's gravity, and 2) automatic rotation of the thrust vector in the pitch and/or yaw direction to cancel aerodynamic drag and/or side forces. In this regard, the pitch and yaw channels will automatically rotate the thrust vector as commanded by electronic signals. These signals originates from attitude displacement gyros which sense LTA-9 pitch and yaw attitude, and acceleration errors which arise from comparison of computed LEM mission horizontal acceleration with output of the horizontal accelerometers.

A typical block diagram indicating the functioning of the jet engine thrust vector control system in the pitch plane is shown in figure 5-25. The functioning of the thrust vector control system is identical in the yaw plane except that control of the direction of the thrust vector is accomplished by rotation of tail-pipe-mounted vanes instead of rotation of the tail pipes.

From the block diagram representing the control system, the following transfer function is obtained for tail pipe angle output to command input (close loop):

$$\frac{\theta_{tp}}{\theta_c} = \frac{\dfrac{K_{am}}{s(\tau_m s+1)} \dfrac{K_m}{s^2} \dfrac{K_g}{I_{t_p}} \dfrac{K_{dtp}}{}}{1 + \dfrac{K_{am} K_{dm}}{s(\tau_m s+1)} + \dfrac{K_m K_{rm} s}{s(\tau_m s+1)} + \dfrac{K_r K_m K_g}{s3 (\tau_m s+1) I_{t_p}} + \dfrac{K_{dtp} K_m K_{am} K_g}{s3 I_{t_p} (\tau_m s+1)}}$$

From the closed loop transfer function, the following characteristic equation is obtained:

$$s^4 + \frac{(I_{tp} + K_m K_{rm})}{\tau_m} s^3 + \frac{(K_{am} K_{dm})}{\tau_m} s^2 + \frac{(K_{rtp} K_m K_g)}{\tau_m} s + \frac{(K_{am} K_{dtp} K_m K_g)}{\tau_m}$$

The system is designed to respond with a faster time constant than that of the LEM RCS since it is desired that the jet engine thrust vector be reoriented to the vertical at a faster rate than the LEM RCS orients the LTA-9 to the desired pitch attitude. It has been tentatively established that the LEM RCS operating in the rate command mode will have a .4 second time constant. (Based upon results of LEM simulator studies to be performed in the near future, this time constant might be altered. This time constant can then be duplicated by a judicious selection of gains in LTA-9 control). On the basis of the current LEM configuration the following fourth order polynomial was selected to represent the thrust vector control system closed loop characteristic equation. With this polynominal, the low frequency root will be dominant, and the closed loop system will respond with a closed loop time constant of 0.25 seconds with no appreciable effect expected from the higher frequency roots.

$$(.25\ s + 1)\ (.05\ s + 1)\ \left(\frac{s}{(15)2} + \frac{2(.7)}{(15)} s + 1\right)\ (18000)$$

or:

$$s^4 + 45\ s^3 + 809\ s^2 + 7080\ s + 18000$$

Equating the coefficients of the system closed loop characteristic equation and the model polynominal the following relationships are obtained for the system gains:-

$$\frac{I_{tp} + K_m K_{rm}}{\tau_m} = 45 \quad \frac{K_m K_{dm}}{\tau_m} = 809 \quad \frac{K_{rtp} K_m K_g}{\tau_m} = 7080 \quad \frac{K_{am} K_{dtp} K_m K_g}{\tau_m} = 18000$$

Section 5.5.6.2. has presented a value for a tail pipe inertia of $I_{tp} = 1.0$ slug - ft ^{2} and a power capability of 57 in.-lb/sec. is required from the actuator. Designing the closed loop transfer function of the actuator as:

$$\frac{.475}{\left(\frac{s^2}{(28.4)2} + \frac{2(.79)}{28.4} s + 1\right)}$$

The following gains are selected for the actuator and gearing gains, and are obtained by satisfying the first two coefficients relationships for the closed loop characteristic equation for the engine thrust vector control system established in the previous paragraph.

$K_m = 23$, $K_g = 10$, $K_{dm} = 2.1$, $K_{rm} = .074$ $\tau_m = .06$

The loop feed backs gains are calculated to be:

$K_{rtp} = 9.3$, $K_{dtp} = 4.7$.

The final closed loop transfer function for the engine thrust vector control system is:

$$\frac{\theta_{tp}}{\theta_c} = \frac{.213}{(.25\ s + 1)\ (.05\ s + 1)\ \ (.00444\ s^2 + .0933\ s + 1)}$$

This analysis relates to a linear representation of the closed loop behavior of the engine thrust vector control system where selection of system gains to obtain the desired system stabilization and response is straight forward. Future effort will be directed toward a more complete study utilizing the analog computer to represent and analyze component non-lineorities and their effects on system response and stabilization.

5.5.4.2 Jet Engine Throttle Control System

During the LTA-9 landing maneuver, the thrust of the jet engines is required to be automatically maintained in a vertical direction at a level approximately equal to 5/6 of the LTA-9 weight, less the magnitude of the vertical aerodynamic lift developed on the vehicle due to movement in the atmosphere. In this regard, the jet engine throttle system will throttle the engine in response to acceleration error signals which arise by comparison of the computed LEM control vertical acceleration with the output of the vertical accelerometer. The block diagram illustrating the operation of the engine throttle control system is shown in figure 5.2.6.

From the block diagram representing the control system, the following transfer function is obtained for jet engine vertical acceleration output for command acceleration input (closed loop):

$$\frac{\ddot{X}_{ba}}{\ddot{X}_c} = \frac{K_{am} K_m K_g K_{th} K_e}{S^2(\tau_m S+1)(\tau_e S+1) m \cos \theta_{tp}}$$

$$\frac{}{1 + \frac{K_m K_{dm}}{S(\tau_m S+1)} + \frac{K_m K_{rms}}{S(\tau_m S+1)} + \frac{K_{am} K_m K_g K_{th} K_e K_{ath}}{S^2(\tau_m S+1)(\tau_e S+1) m \cos \theta_{tp}}}$$

From the closed loop transfer function the following characteristic equation is obtained representing system response behavior:

$$S^4 + S^3\frac{(\tau_m + \tau_e + K_m K_{rm})}{T_m T_e} + S^2\frac{(1 + K_m K_{rm} + K_m K_{dm} \tau_e)}{\tau_m \tau_e}$$

$$+ S\frac{(K_m K_{dm})}{(\tau_e \tau_m)} + \frac{K_m K_{am} K_g K_{th} K_e K_{ath}}{\tau_m \tau_e m \cos \theta_{tp}}$$

In order to obtain the loop gains to stabilize this system, the response characteristics of the throttle actuator and the jet engine are to be defined.

The response characteristics of the SJ-132 jet engine as obtained from the engine manufacturer is represented by the transfer function defining the incremental engine thrust per radian throttle deflection about the 95% engine r.p.m., 80% maximum thrust condition, and is as such:

$$\frac{\Delta T}{\delta_{T_h}} = \frac{K_e}{S(T_e S+1)}$$

where K_e = .674 lb/rad throttle

T_e = .826 seconds

The closed loop response of the throttle actuator is defined by the following transfer function:

$$\frac{1/K_{dm}}{\frac{(\tau_m)}{(K_d K_m)} S^2 + \frac{(1 + K_{rm} K_m)}{K_d K_m} S + 1}$$

Section 5.5.6.2 has specified a motor power capability of 3.125 in.-lbs/sec. and a motor open loop time constant of τ_m = .06 seconds to meet actuation requirements for the throttle. A closed loop actuator time constant of 0.25 seconds is selected to be faster than the engine response time constant, which is .826 seconds. The following gains for the actuator are selected.

$$K_m = 1.25, \quad K_{dm} = 3.85, \quad K_{rm} = .35, \quad \tau_m = .06$$

from which the final transfer function of the actuator closed loop response is as follows:

$$\frac{.260}{(.25\ s + 1)(.05\ s + 1)}$$

In order to select a value for the acceleration feedback gain, K_{ath}, and obtain the closed loop characteristics for the engine throttle system, it is recognized that the tail pipe angle, θ_{tp}, is constrained to travel $\pm$ 30° about the neutral position; therefore, since $1.00 \geq \cos\theta_{tp} \geq .866$. The assumption that $\cos\theta_{tp} = 1$, is made.

Substituting the selected values for the jet engine and actuator characteristics established in the previous paragraphs and considering the LTA-9 at the touchdown condition, $m = 225$ slug - ft^2, the closed loop transfer function becomes:

$$\frac{.589\, K_{am} K_{th}}{S^4 + (25.21)S^3 + (190.1)S^2 + (96.8)S + .589\, K_{am} K_{th} K_{ath}}$$

The following selections are made for the remaining gains:

$$K_{th} = 1.0, \quad K_{am} = 20., \quad \text{and } K_{ath} = 7.41$$

The closed loop equation of the jet engine throttle control system at the touch down is:

$$\frac{\ddot{X}_{ba}}{\ddot{X}_c} = \frac{.135}{\left(\frac{S^2}{(.995)^2} + \frac{2(.413)}{(.995)} S + 1 \right)(.227S + 1)(.05S + 1.)}$$

At the hover condition, where $m = 290$ slug - ft^2, the closed loop transfer function is:

$$\frac{\ddot{X}_{ba}}{\ddot{X}_c} = \frac{.135}{\left(\frac{S^2}{(.884)^2} + \frac{2(.526)}{(.884)} S + 1 \right)(.232S + 1)(.05S + 1)}$$

As indicated for the transfer function for the closed loop throttle control system, the closed loop response will be that of a second order system whose dominant resonant frequency and damping will vary through the range of .884 to .995 r.p.s. and .526 to .413 from hover to touchdown, respectively.

The analysis of this system indicates that the throttle control can be stabilized to accommodate the acceleration error commands with good response characteristics, however it is to be recognized that the system has been linearized to facilitate this preliminary analysis. A more complete analog similation of the coupled engine throttle control system - thrust vector control system is necessary in order to ascertain the effects of component non-linearities on system stability.

5.5.4.3. - Auxiliary Moment Control System

5.5.4.3.1 - LEM RCS Coupled System - During the LTA-9 landing maneuver, the auxiliary moment control system is required to automatically supplement the moment producing capability of the LEM RCS on the LTA-9 in the earth's atmosphere such that the LEM handling characteristics expected in the lunar atmosphere are matched. To obtain this effect, the auxiliary moment control system is considered to be coupled to the LEM RCS. This coupled system is to respond with the lunar LEM RCS closed loop time constant and control angular acceleration despite the undesirable moments produced by LTA-9 aerodynamics and c.g. shift. A typical block diagram indicating the functioning of the selected bleed jet moment control system as coupled to the LEM RCS in the pitch attitude-hold mode is shown in the figure 5-26. Functioning of the bleed jet moment control system in the roll and yaw modes is identical. No attempt was made to consider the control coupling between body axes at this time since an extensive analog simulation would be required to represent non-linear rigid body cross coupling motions. A linear analysis was performed to arrive at a set of loop gains for a stable system and to obtain a system response which is satisfactory.

The characteristic equation of the coupled closed loop system in the attitude-hold mode as obtained from the block diagram is as follows:

$$
\begin{aligned}
&S^4(I_y \tau_m) + S^3 (I_y + I_y K_m K_{rm} + K_{rrj} K_{trj} l_{rj} \tau_m) \\
&\quad + S^2 (I_y K_{am} K_m K_{dm} + K_{am} K_m K_{tbj} l_{bj} K_{abj} \\
&\quad + K_{drj} K_{trj} l_{rj} \tau_m + K_{rrj} K_{trj} l_{rj}) \\
&+S (K_{am} K_m K_{tbj} l_{bj} K_{rbj} + K_{drj} K_{trj} l_{rj} \\
&\quad + K_m K_{rm} K_{rrj} K_{trj} l_{rj} + K_{am} K_m K_{dm} K_{rrj} K_{trj} l_{rj}) \\
&\quad +(K_{am} K_m K_{tbj} l_{bj} K_{dbj} + K_{rm} K_m K_{drj} K_{trj} l_{rj} \\
&\quad\quad +K_{am} K_m K_{dm} K_{drj} K_{trj} l_{rj})
\end{aligned}
$$

To illustrate the calculation of the loop gains, it is desirable that the coupled system has the same response characteristics designated for the LEM RCS in the attitude-hold control mode, that is, with a closed loop resonant frequency of 2.25 C.P.S and a damping ratio of 0.56. To meet this requirement the following polynomial was selected to represent the characteristic equation of the closed loop coupled system.

$$\left(S^2 + 2(.56)(2.25)^2 \right)\left(S^2 + 2(.7)(30)S + (30.0)^2 \right)$$

which can be rewritten as:

$$s^4 + 44.5s^3 + 1010.9s^2 + 2480.6s + 4554.3$$

It is anticipated that the high frequency complex roots will have no significant effect on the coupled system closed loop response.

The following gain constants have been established for the LEM RCS to obtain the aforementioned response characteristics, that is, $\omega_{rj} = 2.25$, $\zeta_{rj} = .56$, in the attitude-hold, at the hover flight condition:

$$K_{trj} = 5065;\ l_{rt} = 5.538;\ K_{rrj} = .5$$
$$K_{drj} = 1.0,\ I_y = 5610 \text{ slug-ft}^2.$$

Equating coefficients for the closed loop characteristic equation and the desired response polynominal, and substituting values for the LEM RCS gains, and using an open loop bleed jet actuator time constant of $\tau_m = .04$ sec. as specified in section 5.5.6.2, the following relationships are calculated. They pertain to the gains required in the bleed jet control loops and the closed loop actuator feedback loops.

$$K_m K_{rm} = .681$$
$$K_{am} K_m K_{dm} + A_{bj} .(000178) K_{abj} = 40.44$$
$$K_{am} K_m K_{dm} + A_{bj} .(000713) K_{rbj} = 36.94$$
$$K_{am} K_m K_{dm} + A_{bj} (.0000357) K_{dbj} = 35.71$$
$$A_{bj} = K_{am} K_m K_{tbj} l_{bj}$$

To meet actuation requirements for the bleed jet valves, a motor power capability of .75 in-lb/seconds is specified in section 5.5.6.2.

Considering the transfer function of the actuator, closed loop, as:

$$\frac{.0625}{\frac{s^2}{(25)^2} + \frac{2(.82)}{(25)} s + 1}$$

The following constants are calculated:

$$K_{am} = 1.0 \qquad K_{dm} = 16.00 \qquad K_{rm} = .436 \qquad K_m = 1.563$$

Substituting these values in the expressions involving the bleed jet systems gains and with a value for l_{bj} = 19 ft., the following values for the bleed jets system gains are obtained:

$$K_{am} = 1.0,\ K_{abj} = 2.59,\ K_{rbj} = 5.00,\ K_{bbj} = 8.97,\ K_{tbj} = 1128.$$

The closed loop transfer function for the coupled bleed-jet moment - LEM RCS control system, at the take-off condition is:

$$\frac{\ddot{\theta}_{ba}}{\theta_c} = \frac{.0328\,(2.59S^2 + .5S + 1)}{\left(\frac{S^2}{(2.25)^2} + \frac{2(.56)}{(2.25)}S + 1\right)\left(\frac{S^2}{(30)^2} + \frac{2(.7)}{30}S + 1\right)}$$

At the touchdown condition, for I_y = 4410 slug-ft^2, the closed loop transfer function becomes: -

$$\frac{\ddot{\theta}_{ba}}{\theta_c} = \frac{.0416\quad 2.03S^2 + .500S + 1.}{\left(\frac{S^2}{(2.32)^2} + \frac{2(.58)}{2.32}S + 1\right)\left(\frac{S^2}{(25.2)^2} + \frac{2(.65)}{25.2}S + 1\right)}$$

The closed loop transfer function shown above indicates that the coupled system is stable throughout the LTA-9 landing maneuver from hover to touchdown and the response characteristics match those of the LEM RCS in the attitude-hold mode. The dominant low frequency complex pair exhibit a variation of resonant frequency between 2.25 to 2.32 r.p.s and damping ratio between .56 to .58. This system response is possible with a set of feedback loop gains which are held constant throughout the flight range. Future effort would be directed toward a more complete analog computer program of the coupled system with non-linear representation of the system to ascertain their effect on system stability and performance response.

5.5.4.3.2 Bleed - Jet Moment Control System - Manual Mode - Attitude control of the LTA-9 from takeoff to hover prior to the LEM landing manuever or in event of failure of the LEM RCS is accomplished by use of the bleed jet moment control system under manual control. From the block diagram of figure 5-27, the following transfer function is obtained which represents the closed loop response of the bleed-jet moment control system to an attitude command in the pitch atitude-hold and rate command modes:

ATTITUDE-HOLD

$$\frac{\theta_{ba}}{\theta_c} = \frac{K_{am}\ K_m\ K_{tbj}\quad bj}{(I_y \tau_m)s^4 + (I_y + K_m\ K_{rm} I_y)s^3 + (K_m\ K_{dm} I_y)s^2 + (K_{am}\ K_m\ K_{tbj}\ l_{bj}\quad K_{rbj})s + (K_{am}\ K_m\ K_{tbj}\ l_{bj}\quad K_{dbj})}$$

RATE-COMMAND

$$\frac{\dot{\theta}_{ba}}{\dot{\theta}_c} = \frac{K_m\ K_m\ K_{tbj}\ l_{bj}}{s(I_y \tau_m)s^3 + (I_y + K_m\ K_{rm} I_y)s^2 + (K_m\ K_{dm}\ I_y)s + K_a\ K_m\ K_{tbj}\ l_{bj}\ K_{dbj})}$$

By use of the loop gain constants obtained by stabilization of the coupled bleed jet moment-LEM RCS system, the following transfer functions were obtained for the closed loop response of the bleed jet moment control system at the takeoff, and touchdown flight conditions for the LTA-9.

ATTITUDE-HOLD MODE
TAKE-OFF:

$$\frac{\theta_{ba}}{\theta_c} = \frac{(.111)}{\left(\frac{s^2}{(1.75)^2} + \frac{2(.41)}{(1.75)}\ s + 1\right)\left(\frac{s^2}{(2.37)^2} + \frac{2(.85)}{(23.7)} + 1\right)}$$

RATE-COMMAND
TAKE-OFF

$$\frac{\dot{\theta}_{ba}}{\dot{\theta}_c} = \frac{(.200)}{s(.781\ s + 1)\left(\frac{s^2}{(24.)^2} + \frac{2(.85)}{(24.)^2}\ s + 1\right)}$$

TOUCHDOWN

$$\frac{\theta_{ba}}{\theta_c} = \frac{(.200)}{s(.584\ s + 1)\left(\frac{s^2}{(23.6)^2} + \frac{2(.85)}{(23.6)}\ s + 1\right)}$$

Response of the bleed jet control moment system in both attitude-hold and rate-command modes is indicated to be well stabilized. In the rate command mode the dominant response time constant is held within the range of .584 to .781 seconds throughout the flight range. In the attitude-hold mode, the dominant response frequency and damping ratio is held within the 1.51 to 1.75 rps and .37 to .41 respectively. These characteristics are obtained with one set of system loop gains, which are held constant throughout the flight operational range.

5.5.4.4 List of Symbols

θ , pitch attitude, radians
ϕ , roll attitude, radians
ψ , yaw attitude, radians
X , vertical displacement, ft.
Z , horizontal displacement, ft.
Y , side displacement, ft.
T , thrust, lbs.
M , vehicle mass, slugs
I_y , pitch inertia, slugs-ft.^{2}
I_x , roll inertia, slugs-ft.^{2}
I_z , yaw inertia, slugs-ft.^{2}
I_{tp} , tail pipe,inertia slugs-ft.^{2}
K_{am} , amplifier gain,volt/volt
K_g , reduction gearing,ratio rad/ratio
K_m , motor gain,rps/volt
K_a , acceleration feedback,gain volts/rps^2
K_d , position feedback gain,volts/rad.
K_r , rate feedback gain,volts/rps
K_t , thrust sensitivity, $\frac{\#\text{thrust.}}{\text{rad.}}$
K_e , engine gain,#thrust/rad. throttle
ω , frequency, rps
ζ , damping ratio
τ , time constant, seconds
l , moment arm, ft.
RCS , reaction control system

Subscripts

m	motor
rj	reaction jet
bj	bleed jet
th	throttle
c	command
ba	body axis
g	gearing
am	amplifier
tp	tailpipe

5.5.5 Handling Qualities

The LTA-9 EEC System has been designated to match the handling characteristics exhibited by the LEM RCS operated in the lunar environment during the terminal descent phase of the manned lunar landing mission. To accomplish this, the EEC bleed jet moment system is so designed to respond to angular acceleration error signals developed during LEM control movements such that the coupled LEM RCS-EEC bleed jet moment will exhibit the same handling characteristics in the earth's environment as obtained with the LEM RCS in the lunar environment. Also the EEC system is designed to exhibit satisfactory handling quality when operating in the manual mode prior to LTA-9 entry into the simulated lunar terminal descent.

The Stillwell handling quality criteria are reproduced in figure 5-28, on which the handling characteristics of the LEM RCS and the EEC in the automatic mode are summarized and compared in the pitch, roll and yaw control modes. As indicated, a favorable comparison is obtained in the acceptable handling quality region of the Stillwell evaluation. For the EEC system operating in the manual mode, satisfactory handling quality is shown for all three control modes.

5.5.5.1 LEM RCS (Lunar Mission)

Attitude control of the LEM during the lunar mission is accomplished by use of the reaction control system (RCS) which operates in two modes, where stability augmentation is provided: (1) manual, rate command, and (2) manual, attitude-hold. The transfer functions describing these modes for pitch control (which are identical for the roll and yaw modes) of the LEM proposal configuration are as follows:

Rate Command:

$$\frac{\theta^\circ_o}{\theta^\circ_c} = \frac{K_{trj}\, l_{rj}/I_y}{S + \dfrac{K_{rrj}\, K_{trj}\, l_{rj}}{I_y}}$$

Attitude Hold:

$$\frac{\theta_o}{\theta_c} = \frac{K_{trj}\, l_{rj}/I_y}{S^2 + \dfrac{K_{trj}\, l_{rj}\, K_{rpj}}{I_y}\, S + \dfrac{K_{trj}\, l_{rj}\, K_{drj}}{I_y}}$$

Contingent upon future simulator studies the rate command control mode was selected to respond with a 0.4 time constant, in the attitude - hold mode, with a response frequency and damping ratio of ω_{RJ} = 2.25 r.p.s. and ζ_{RJ} = .7 at the hover condition. These response characteristics are obtained with rate and displacement feedback gains of K_{RRJ} = .5 and K_{DRJ} = 1.0, and with a RCS torque

capability of 1100 ft/lbs. about three axes, pitch, roll and yaw. These gain selections also exhibit good limit cycle characteristics which is of prime importance in a bang-bang system of this design where reaction fuel expenditure is to be minimized.

The handling characteristics, (control power versus response time constant) for LEM RCS operating in the rate command mode were calculated and shown on the Stillwell Handling Quality Criteria reproduced in figure 5-28.

5.5.5.2 LTA-9 (LEM RCS-EEC Coupled Control)

It is expected that the handling characteristics presented in figure 5-28 for the LEM RCS operating in the lunar environment be matched by the control power and response characteristics of the coupled LEM RCS EEC control system used by the LTA-9 operating in the earth's atmosphere. For the LEM RCS - EEC system gains obtained in section 5.5.4.3, the handling characteristics were calculated and shown on figure 5-28 to show comparison to the LEM RCS handling quality in the lunar atmosphere. As indicated LEM RCS - EEC handling quality falls well within the acceptable region and compares favorably with LEM RCS lunar handling characteristics.

5.5.5.3 LTA-9 (EEC in Manual Mode)

For control of the LTA-9 from take-off to the hover point prior to the terminal LEM mission phase, the EEC system will be used. Calculations were made to obtain the handling characteristics of the LTA-9 during the initial flight phase using the system gains obtained in section 5.5.4.3 EEC system handling quality is shown to fall within the satisfactory region of the Stillwell Criteria on figure 5-28.

5.5.6 Detailed Section & Component Description

5.5.6.1 Major EEC Sections

The major EEC sections include the jet throttle control, jet attitude control and auxiliary moment (trim) control. Each of the three is discussed in the following paragraphs.

(a) Jet Throttle This system consists of a relay amplifier, servomotor, gearing, clutch, manual input summing point and other gearing as required to make it compatible with the engine selected (see figure 5-29). This system receives inputs from both the lunar computer (errors in X) and the jet engine attitude control system. The power required to drive the throttle per engine is 3.12 in-lb/sec at a rate of 0.104 rad./sec. manual control is implemented.

P = (.104) (30) = 3.12 in/lb/sec.; where 30 = torque at throttle valve (in-lb_. The mechanical time constant is approximately .06 sec.

(b) Jet Vector Control Will be used to tilt the tailpipes of the jet engine to accommodate vehicle pitch attitude changes. This system will respond to two inputs. One will be a vehicle attitude change and the other a Z-axis translation acceleration error due to drag. The system is illustrated in Figure 5.30. Since the engine attitude change required to cancel drag is small, the system is sized to a factor of LEM response-to-command inputs (as noted in Table 5-8) and tailpipe intertial characteristics. The electro-mechanical actuator power requirements are:

Torque required = 7.85 ft-lb

Power = (7.85) (.065) = 4.75 $\frac{\text{ft-lb}}{\text{sec.}}$

The tailpipe actuation hardware is illustrated schematically in Figure 5-30. The time constant for this electromechanical device is approximately 0.1 sec.

(c) Auxiliary Moment Control This system consists of an amplifier driven servo motor which is mounted on the bleed-air jet assembly. The jets are illustrated in figure 5-15 and the control system is shown in figure 5-31. In the manual mode, the signals originate from a pilot-operated attitude controller. The output of this controller is an attitude signal which is proportional to controller displacement. In the automatic mode, the system receives acceleration signals which are a function of earth-moon differences. These signals drive a valve servo, thereby, controlling the net torque output.

The power requirements for the servo motor were obtained as follows by considering required control power:

Moment rate required: 1350 ft-lb/sec

Valve rate for this moment: .375 in/sec

Power of motor = F(x) = (2) (.375) = .750 in-lb/sec

The mechanical time constant = .04 sec.

5.5.6.2 Major Components

(a) Lunar Computer is an analog model of the LEM which includes the LEM S & C subsystem, RCS subsystem, the rocket engine, and the vehicle dynamics. Vehicle inertial characteristics will be modified as a function of mass properties change. (see figure 5-32). Signals operating on the computer will result in axial and angular displacement, rate and acceleration outputs that would be experienced by LEM on the moon. This computer will respond to attitude commands about all 3 axes (for simplicity only one axis is shown in the figure). The X-axis translation is a function of rocket thrust on LEM, therefore, the model is so configured. If LEM S & C signals are used, computer simplifications will result because these functions need not be modeled.

(b) Mass Properties Computer is a digital device that will compute a weight change as a function of fuel use. Fuel flow measurement can be effected through use of flow meters or may be computed as a function of throttle position and throttle rate integrated over time. If throttle position is used, the information will be integrated and stored.

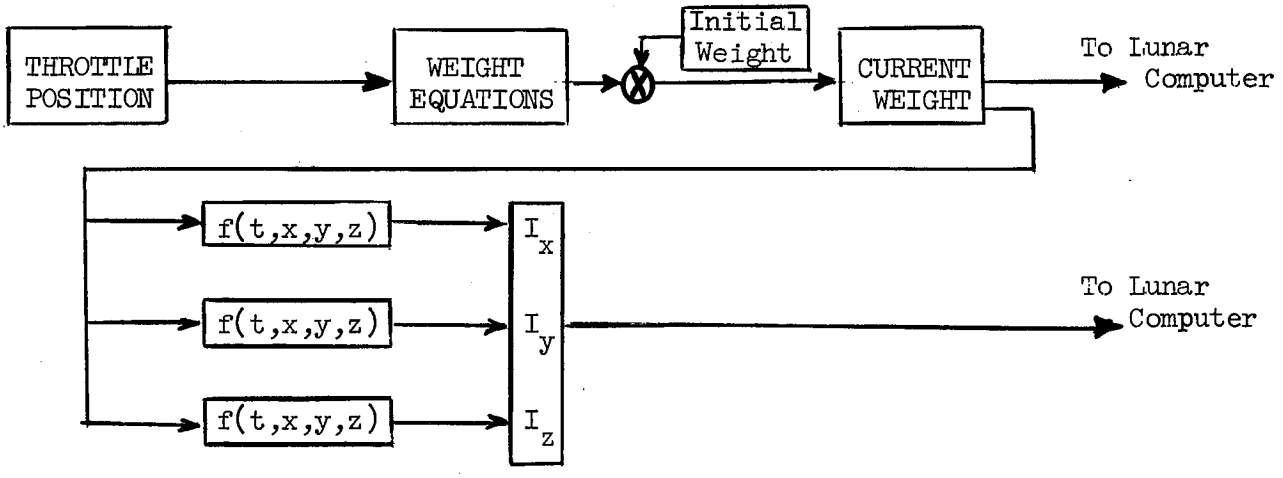


Figure 5-33 MASS PROPERTIES COMPUTER

The change in moment of inertia about the 3 axes can also be programmed as a function of weight change and c.g. shift. Schematically, the system will be arranged as shown in figure 5-33.

(c) Vertical Reference-It is anticipated that the LEM IMU will be used to provide this reference. An alternative is the use of a free gyro. If a free gyro is used, it must have a maximum angular displacement of ± 40 degrees. It will be

erected prior to flight with a bubble pendulus with an accuracy of better than 0.25 degrees. The gyro would be selected to furnish a drift rate of less than 0.1 deg./min. which indicates a maximum error of 0.5 degrees for LTA-9 missions.

(d) Body Accelerometers again, the IMU will be used. The alternate here is the use of two accelerometers. The threshold of such units is less than .01g. One accelerometer per axis can be used together with a resolver chain to give angular as well as linear accelerations.

(e) Controllers The jet thrust controller will be a separate manual control, since simultaneous throttling is required during rocket engine light-off. Engine throttle linkage arrangement will consist of three clutched pairs to permit isolation of one engine pair and manual override in the event of a linkage failure. Since the bleed-air system is used for manual attitude control only during the initial climb and transition, the LEM attitude controller can be time shared for this function especially since there is redundancy in this control.

5.5.6.3 Preliminary Weight and Power Requirements

Component	Weight - lbs. Per Unit	Weight - lbs. Total	Power-Watts Total
Tailpipe actuators	3	36	100
Gearing and linkage for tailpipe drive	2	24	5
Mode Selector switching	5	5	5
S & C Electronics	122	122	290
Lunar computer	40	40	300
Throttle servo actuators	2	12	75
Throttle control electronics	15	20	100
Mass properties computer	5	5	50
Malfunction generator (5 to 10 selection)		6	25
Air-bleed valve actuators	2	12	75
Differential throttling electronics	6	36	50
Power supply	20	40	
Jet engine thrust controller & linkage	20	20	

5.5.7 Emergency Modes

5.5.7.1 Failures

A detailed failure effects analysis is best conducted in the preliminary design phase, however, an initial failure evaluation is in order. The control system is designed with adequate margin to safely handle LTA-9 in the event of a LEM control system malfunction. Investigation of the LTA-9 mission profile results in the following list of potential failures.

From take-off through the hover point

* Manual throttle jam - A manual throttle jam downstream of the controller can be coped with if the engines are controlled in pairs and clutched to the main linkage. In this case, the remaining engines can be controlled to bring the vehicle down safely.
* Malfunction of air-bleed nozzle servo - The attitude controller can be displaced to cancel the undesired control input. Loss of a pair of nozzles means loss of angular control in one direction. In this case, the vehicle can be rotated and the orthogonal pair can be used.
* The LEM RCS can also be used as a back up for partial or complete failure of the bleed air system.

Failures during the terminal descent phase

* If the descent rocket engine or engine control fails, the engine will be shut down and a safe landing made on the EEC. jet engines.
* The RCS experiences a failure, the auxiliary moment control will overcome out-of-trim conditions until a shutdown can be effected.
* An EEC jet engine or jet engine throttle or jet vector attitude control failure necessitates shutdown of the failed engine and the opposite engine to maintain a trimmed condition.
* If the bleed-air system fails, it must be shut-down and a landing initiated using LEM reaction control which has sufficient control power for moderate vehicle velocities.

Failures in the terminal descent phase may be harder to cope with because of detection and isolation problems. Any LEM subsystem malfunction with the exception of a descent engine gimbal failure can be overpowered by the EEC system. Although a gimbal failure cannot be completely cancelled, its effects can be reduced to allow time for a shutdown..A key area for detailed investigation is failure detection in the EEC system.

5.5.7.2 Safety Devices

Maintenance of safe flight under emergency conditions in LTA-9 requires that incipient failures be detected rapidly and action taken before the vehicle attitude becomes critical. From the standpoint of safe ejection it is expected that air in-flight monitoring system will be required which possesses the following capability:

* Comparison of levitation engine thrust and tailpipe angles plus logic circuitry which will shut down two diametrically opposed engines when one engine malfunctions.

* Automatic centering of jet engine thrust vectors in the event of engine attitude servo failures.

* Automatic cut-off of one half of the bleed-air control system in the event of a nozzle failure, leaving the remaining half to provide control to touch down.

In addition, manual override on both engine throttling and control systems will be required in the event of automatic system failures.

5.5.8 Control of All-Rocket Configuration

The all-rocket control subsystem would essentially be the same as that used on the LEM. However, the handling qualities of LEM could not be duplicated because the thrust vector is six times as large as in lunar flight. Because a c.g. shift in LTA-9 produces greater consequences than on LEM, the engine gimbal control must have higher resolution and response rate to cope with the attitude control requirements.

To make the proper vehicle response-attitude relations is not feasible. For example, a small misalignment between the gimbal point and vehicle c.g. will produce both angular and translational accelerations. Compensation for both accelerations cannot be made without altering vehicle attitude from that of the LEM. If these deviations can be tolerated, the all-rocket configuration may provide an acceptable vehicle.

5.5.9 Evaluation Studies

To implement the conceptual LTA-9 control system design discussed in this section, more detailed engineering studies are required. The following list summarizes the major technical areas in which further investigation must be conducted for actual system synthesis.

1. Continuous weight change measuring vs. weight calculation
2. Methods for adjusting 5/6 "g" vector
3. Type of vertical reference to be used
4. Use of LEM body sensors for levitation inputs
5. Differential jet engine throttling vs. bleed air trim system.
6. Emergency mode operation - (malfunction in LEM or levitation)
7. Control requirements during transition period (LEM starting)

8. LEM system malfunction training capabilities
9. Use of LEM electronics vs. duplication vs. model of same.
10. Type of malfunctions to be generated vs. complexity of mechanization.
11. Malfunction vs. frequency of malfunction study to determine what should be programmed.
12. Automatic attitude hold
13. Stability augmentation with air-bleed system
14. Manual throttle mechanization

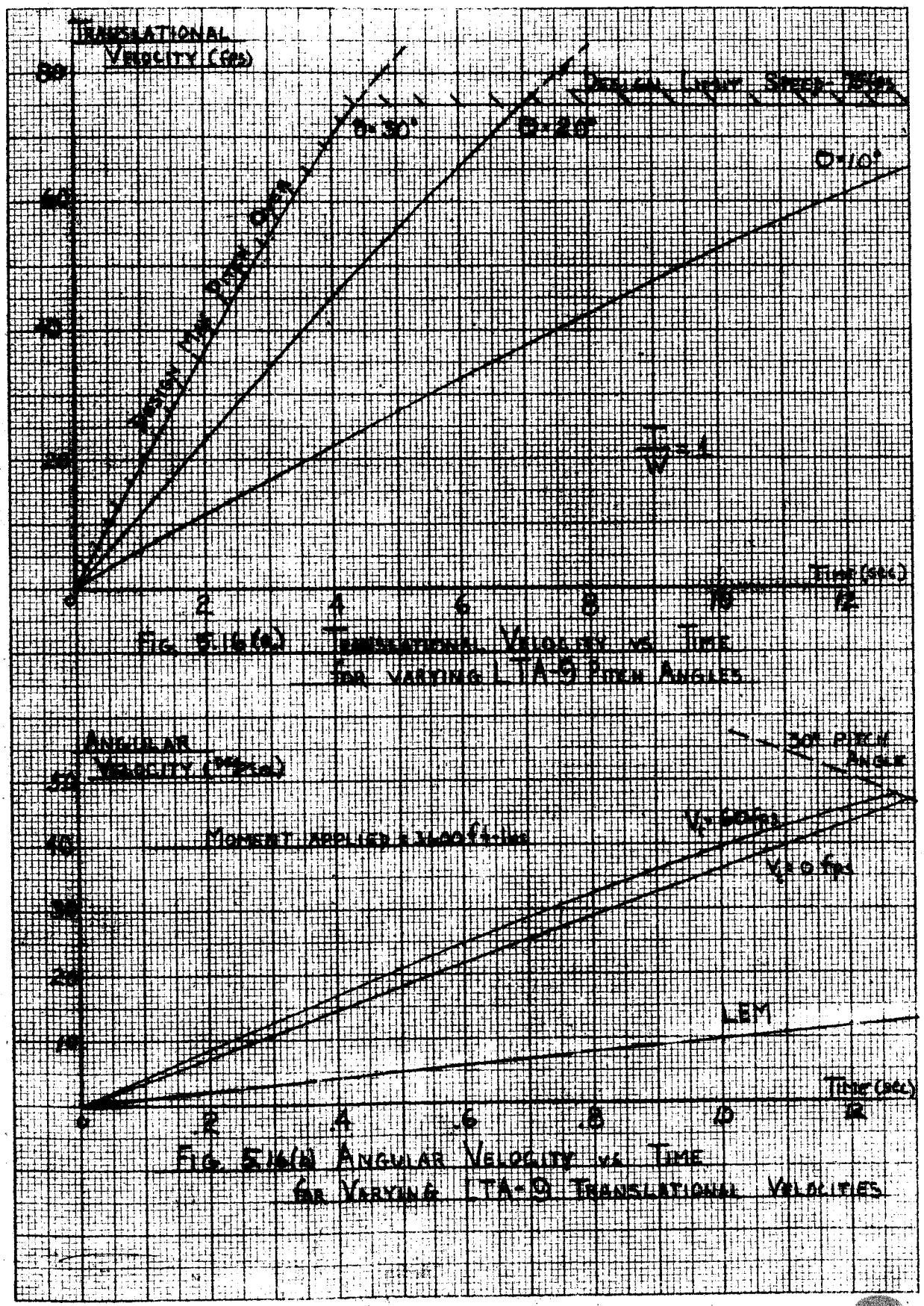


Fig. 5.16(a) Translational Velocity vs. Time for Various LTA-9 Pitch Angles

Fig. 5.16(b) Angular Velocity vs. Time for Various LTA-9 Translational Velocities

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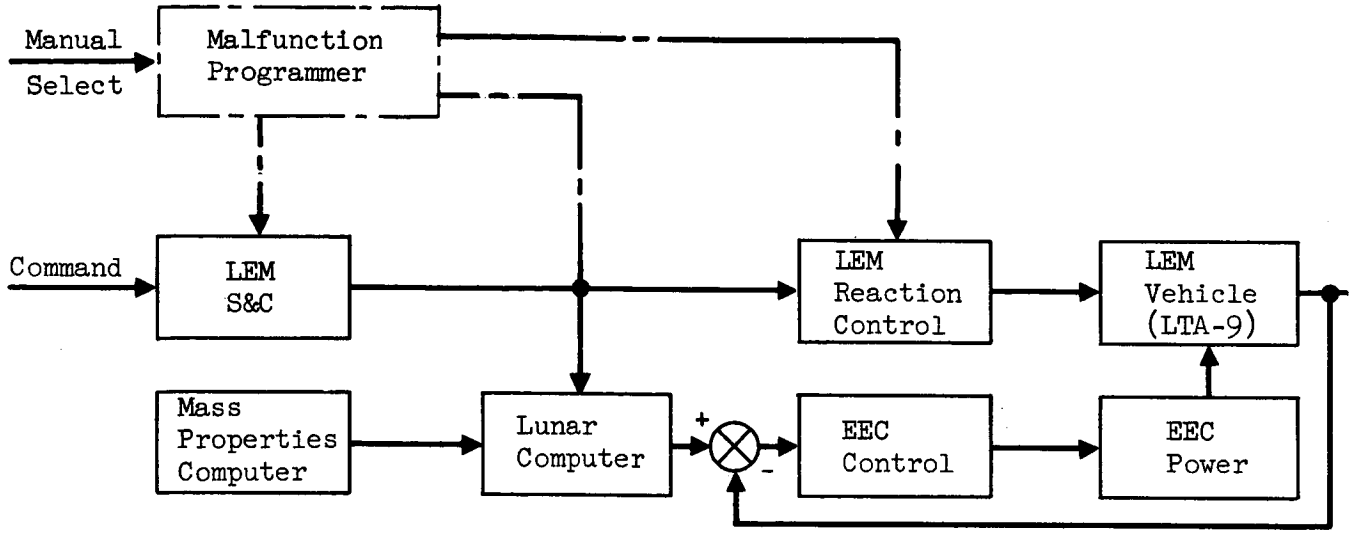
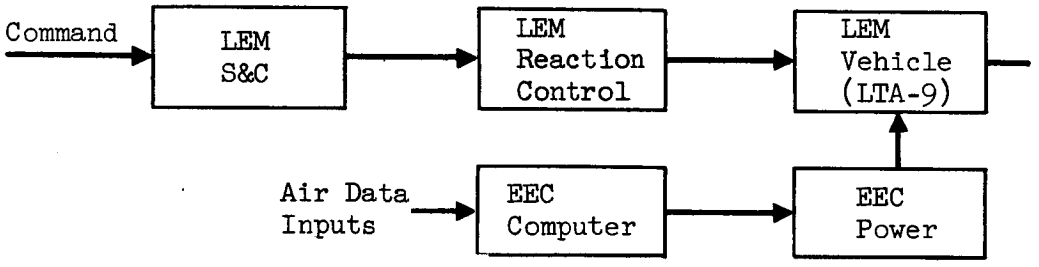
Fig. 5.16

(a) Fully Compensating System



(b) Open Loop



(c) Closed Loop With Malfunction Sensing

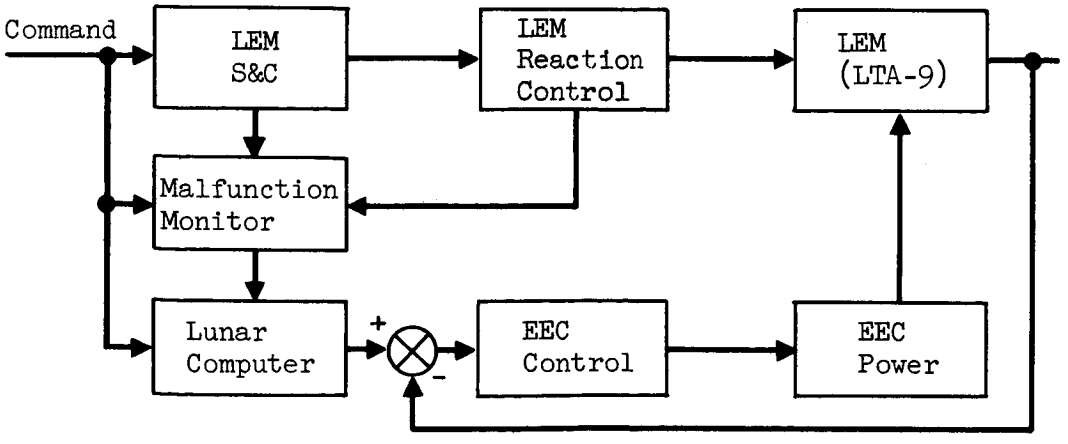


Fig. 5.17 Earth Environment Compensation Subsystem Concepts

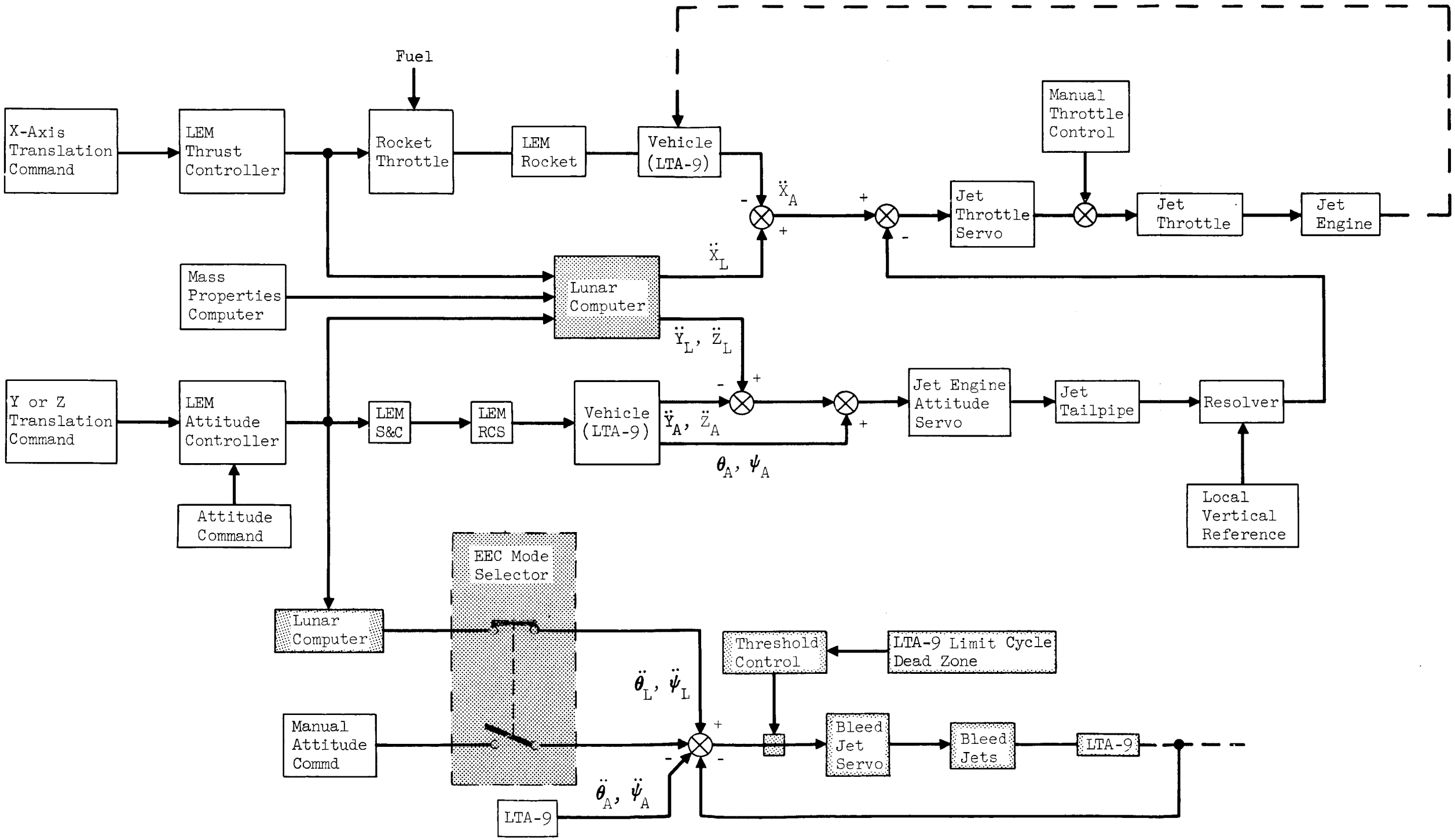
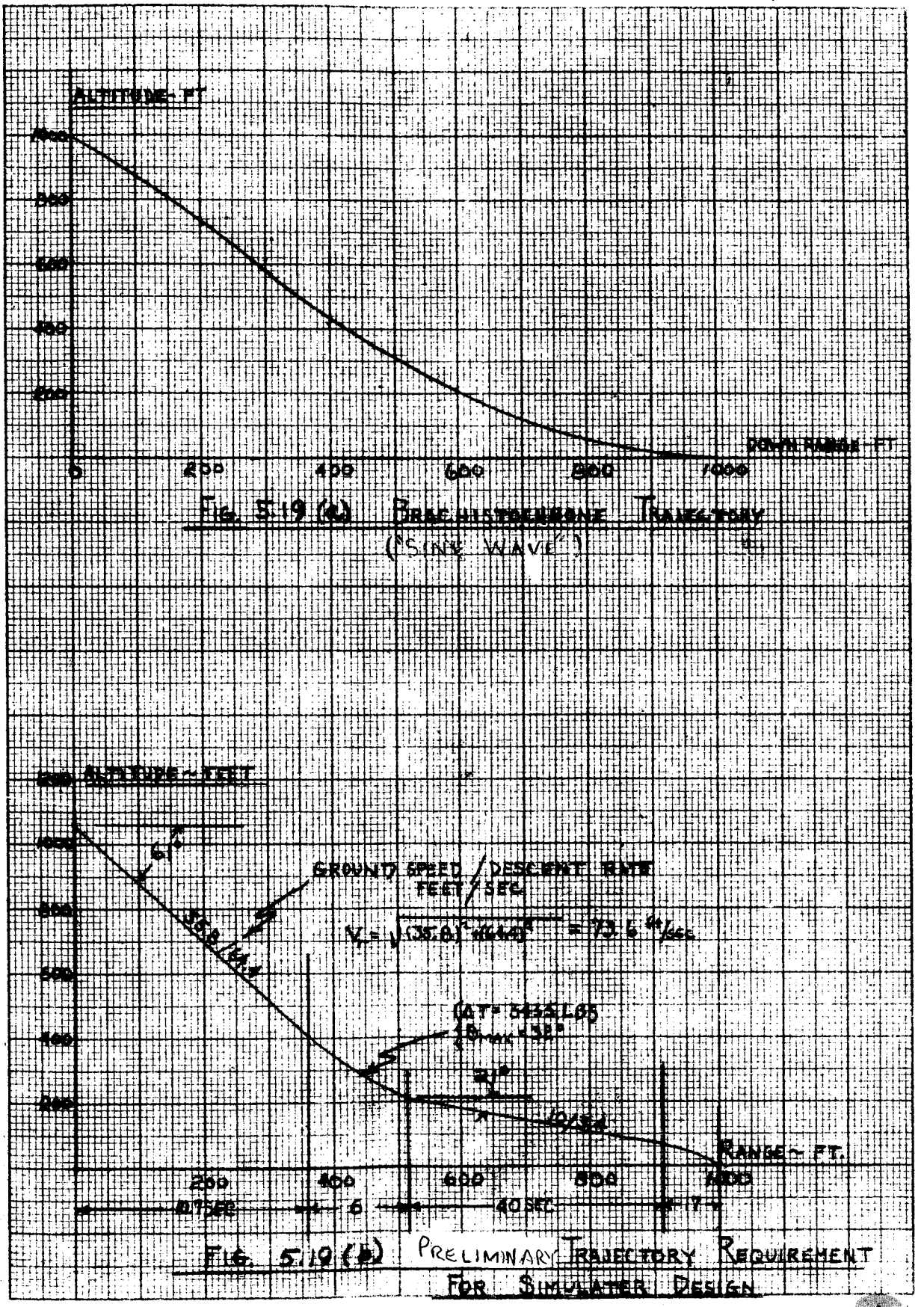


Fig. 5.18 Overall EEC Subsystem Block Diagram


ALTITUDE- FT
DOWN RANGE - FT
0
200
400
600
800
1000
FIG. 5.19 (a) BRACHISTOCHRONE TRAJECTORY
("SINE WAVE")
ALTITUDE - FEET
GROUND SPEED / DESCENT RATE
FEET / SEC.
61°
31°
RANGE - FT.
200
400
600
800
1000
6
40 SEC.
17
FIG. 5.19 (b) PRELIMINARY TRAJECTORY REQUIREMENT
FOR SIMULATOR DESIGN

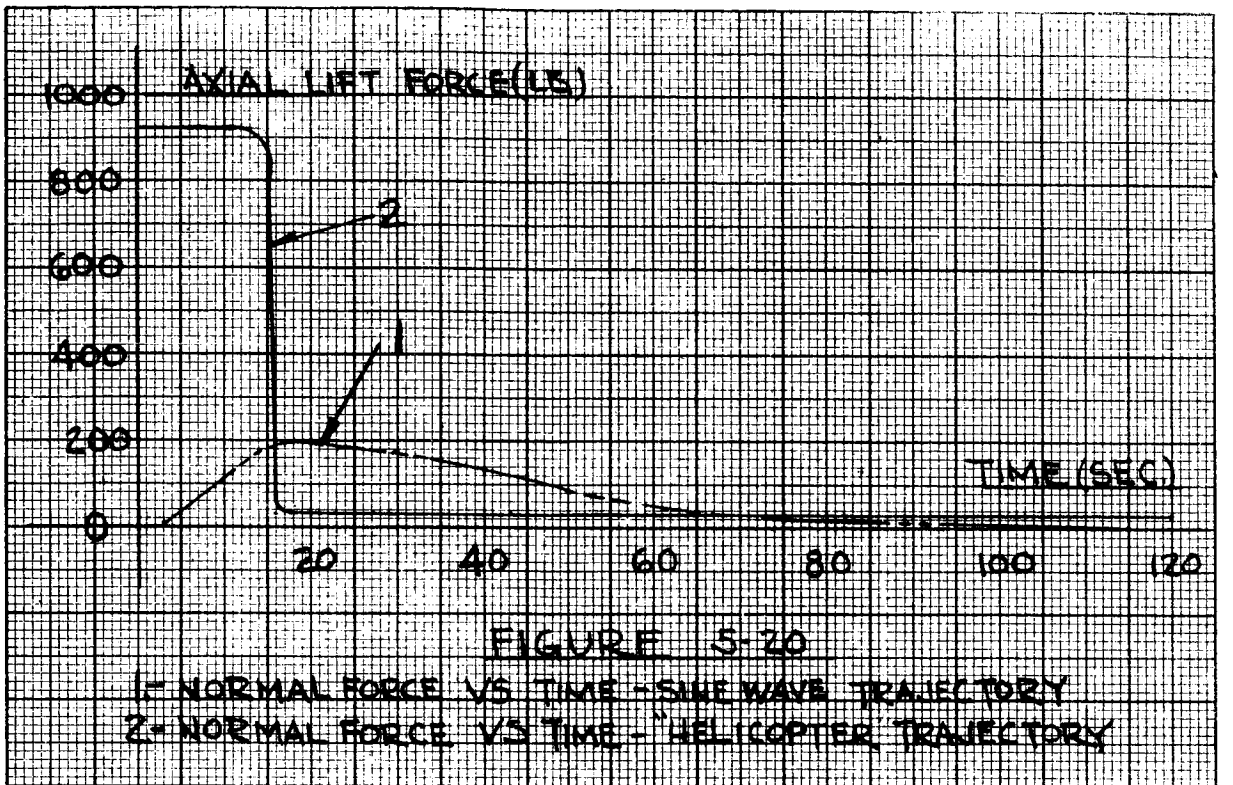


FIGURE 5-20

1- NORMAL FORCE VS TIME - SINE WAVE TRAJECTORY
2- NORMAL FORCE VS TIME - "HELICOPTER" TRAJECTORY

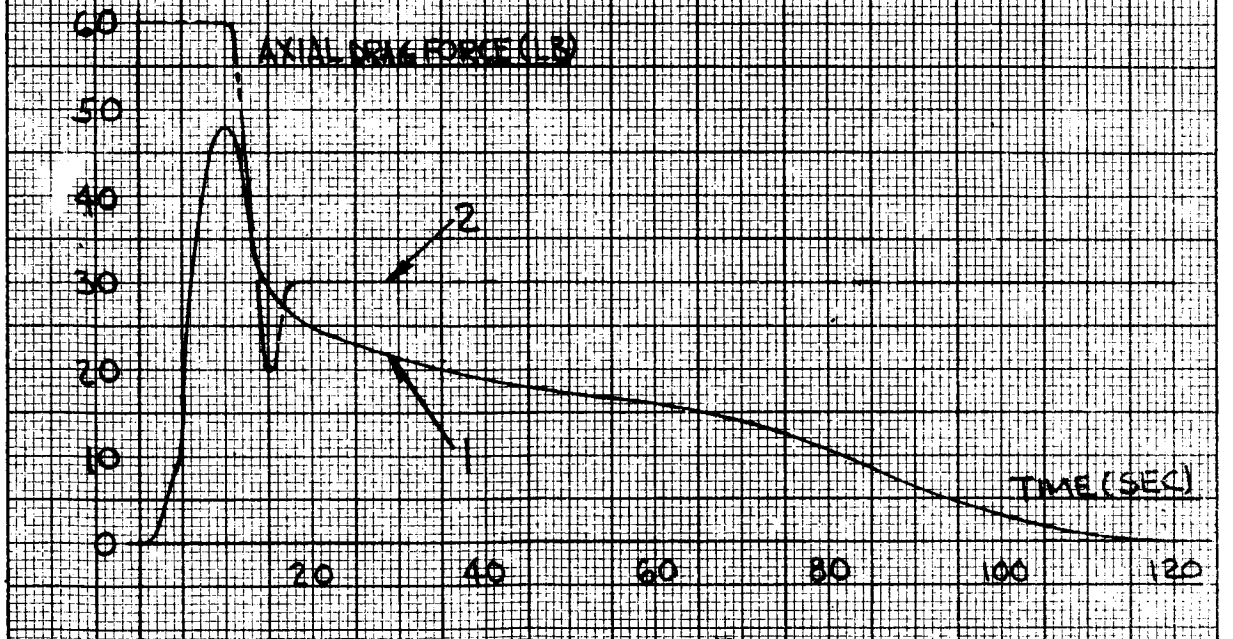


FIGURE 5-21

1- AXIAL DRAG FORCE VS TIME - SINE WAVE TRAJECTORY
2- AXIAL DRAG FORCE VS TIME - "HELICOPTER" TRAJECTORY

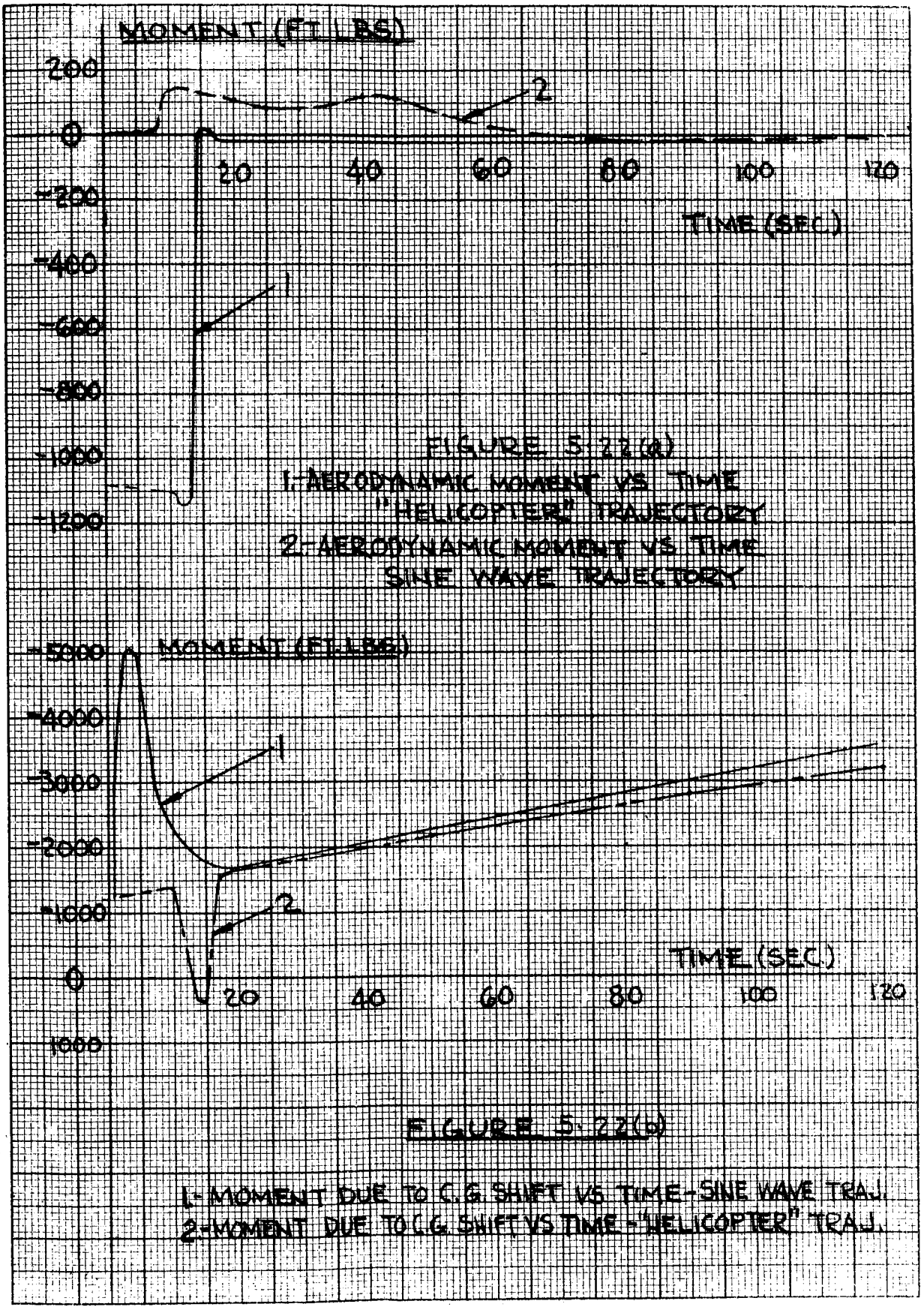


FIGURE 5.22(a)

1- AERODYNAMIC MOMENT VS TIME "HELICOPTER" TRAJECTORY

2- AERODYNAMIC MOMENT VS TIME SINE WAVE TRAJECTORY

FIGURE 5.22(b)

1- MOMENT DUE TO C.G. SHIFT VS TIME - SINE WAVE TRAJ.

2- MOMENT DUE TO C.G. SHIFT VS TIME - "HELICOPTER" TRAJ.

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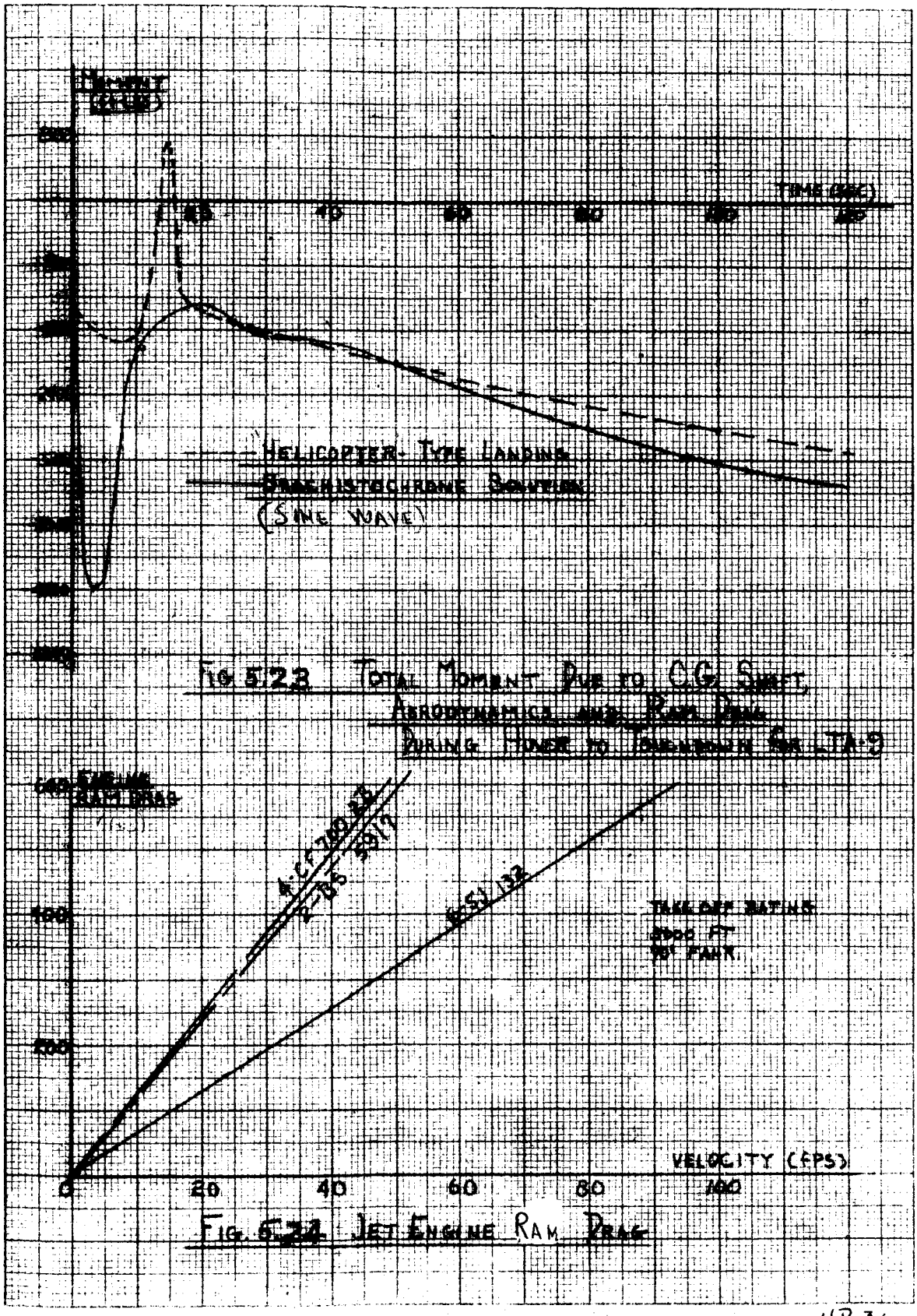


FIG. 5.23 TOTAL MOMENT DUE TO C.G. SHIFT, AERODYNAMICS AND RAM DRAG DURING HOVER TO TOUCHDOWN FOR LTA-9

FIG. 5.24 JET ENGINE RAM DRAG

H.B. 3/9

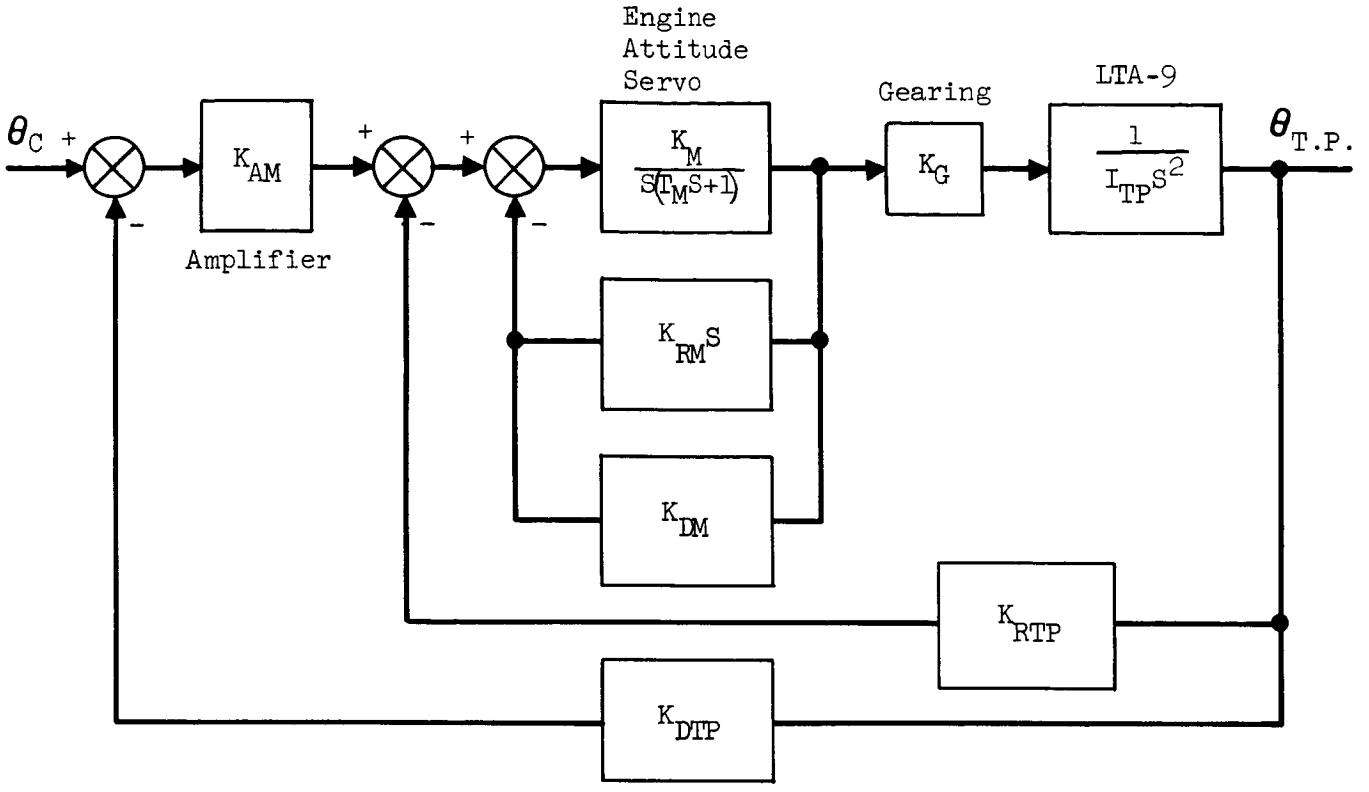


Fig. 5.25 Jet Engine Thrust Vector Control Loop

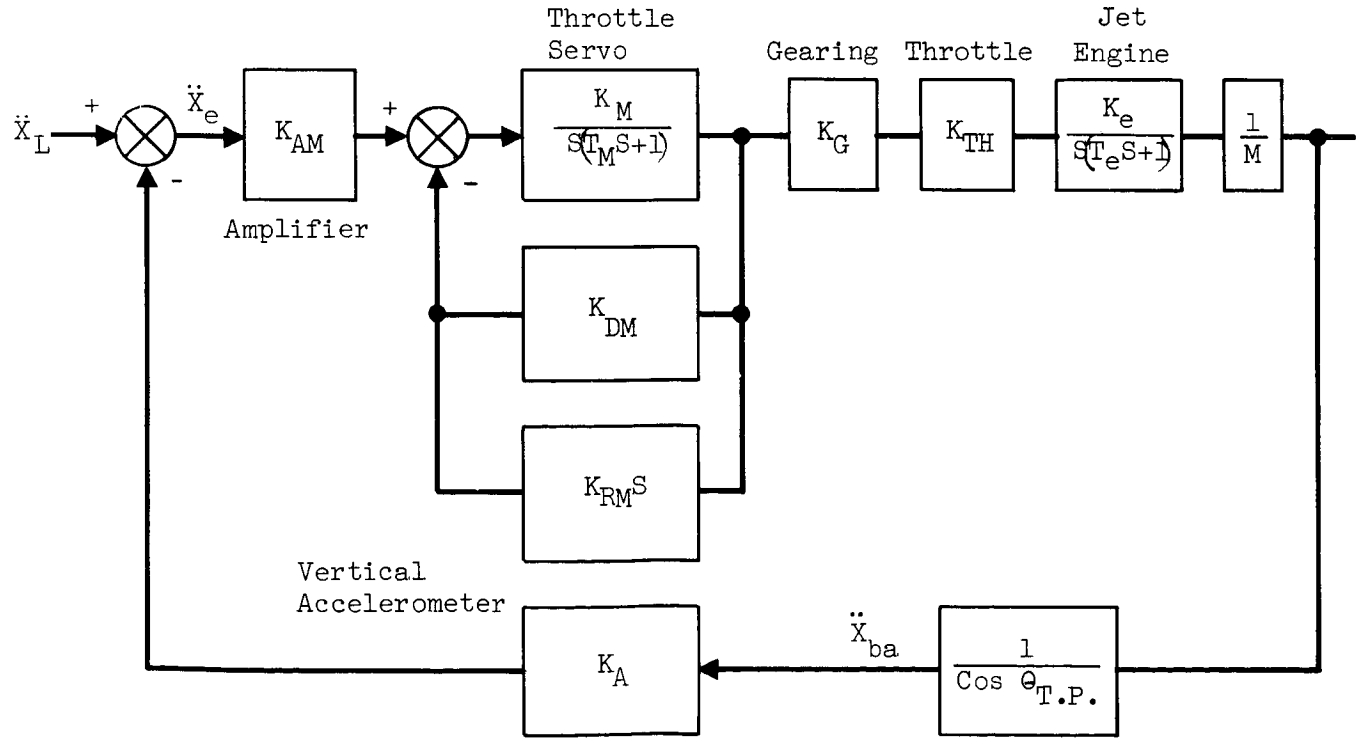
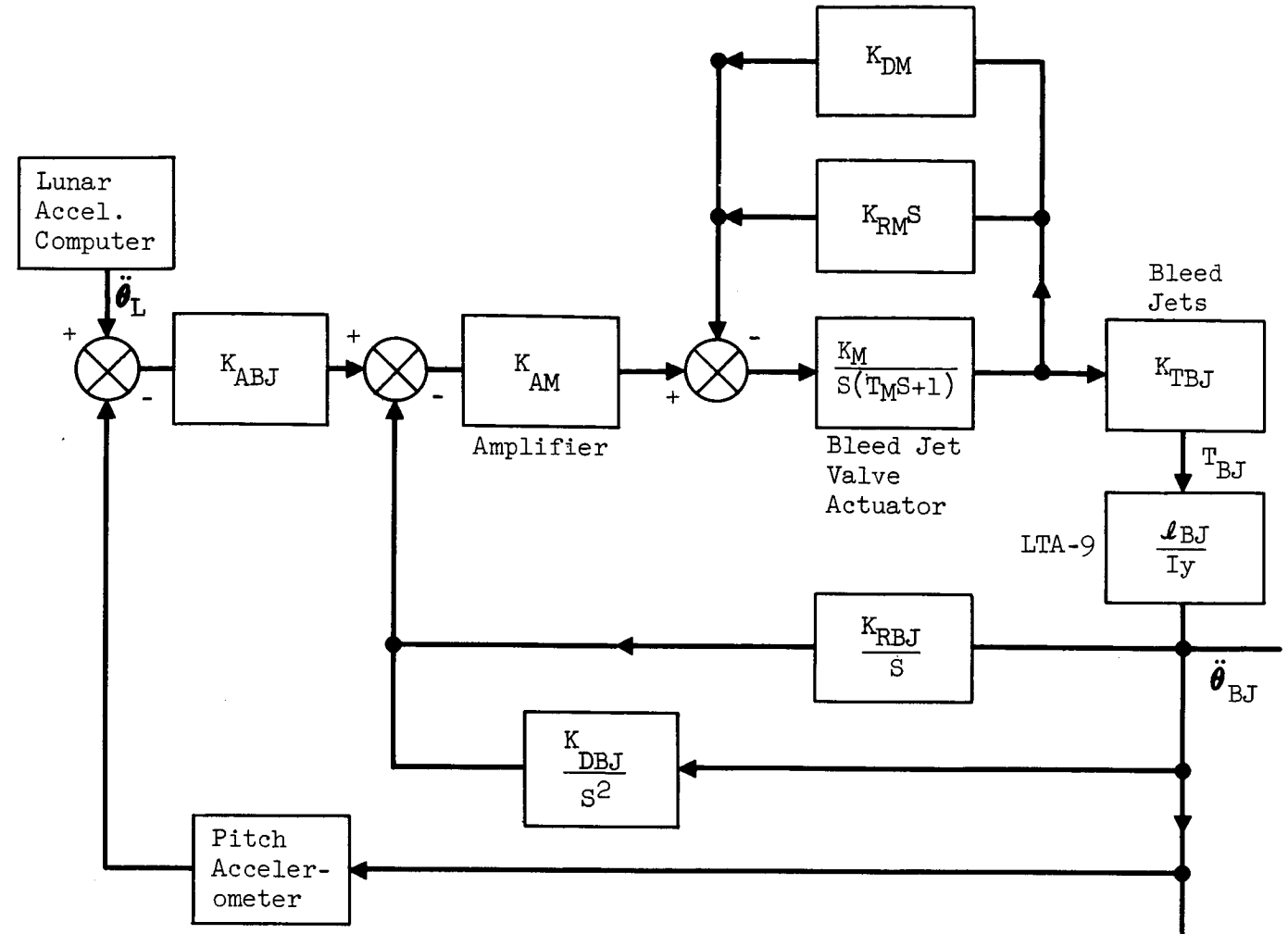
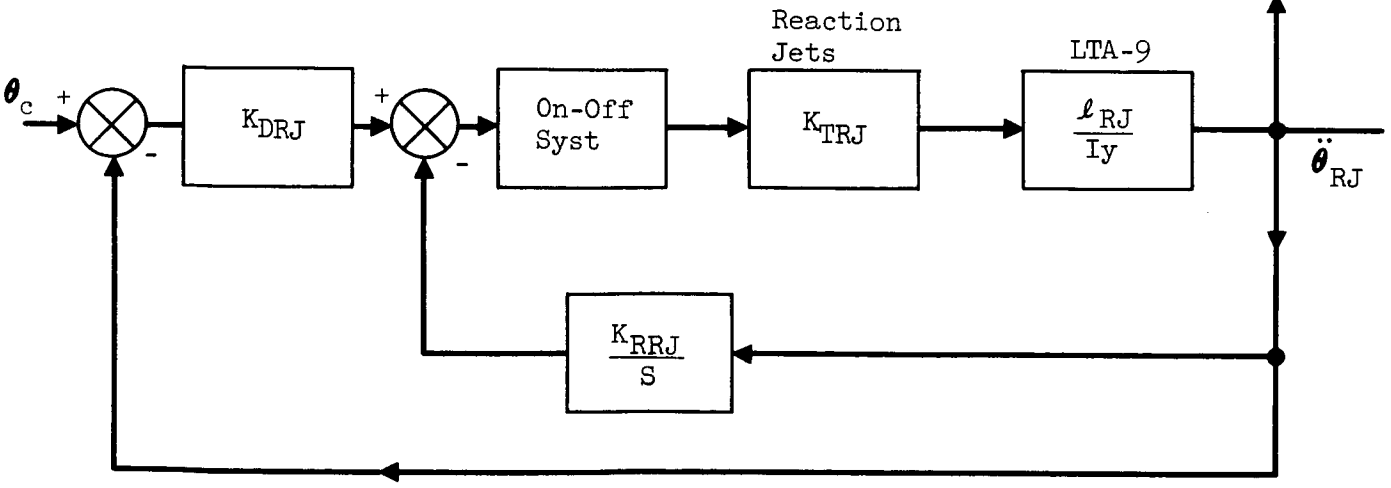


Fig. 5.26 Jet Engine Throttle Control Loop

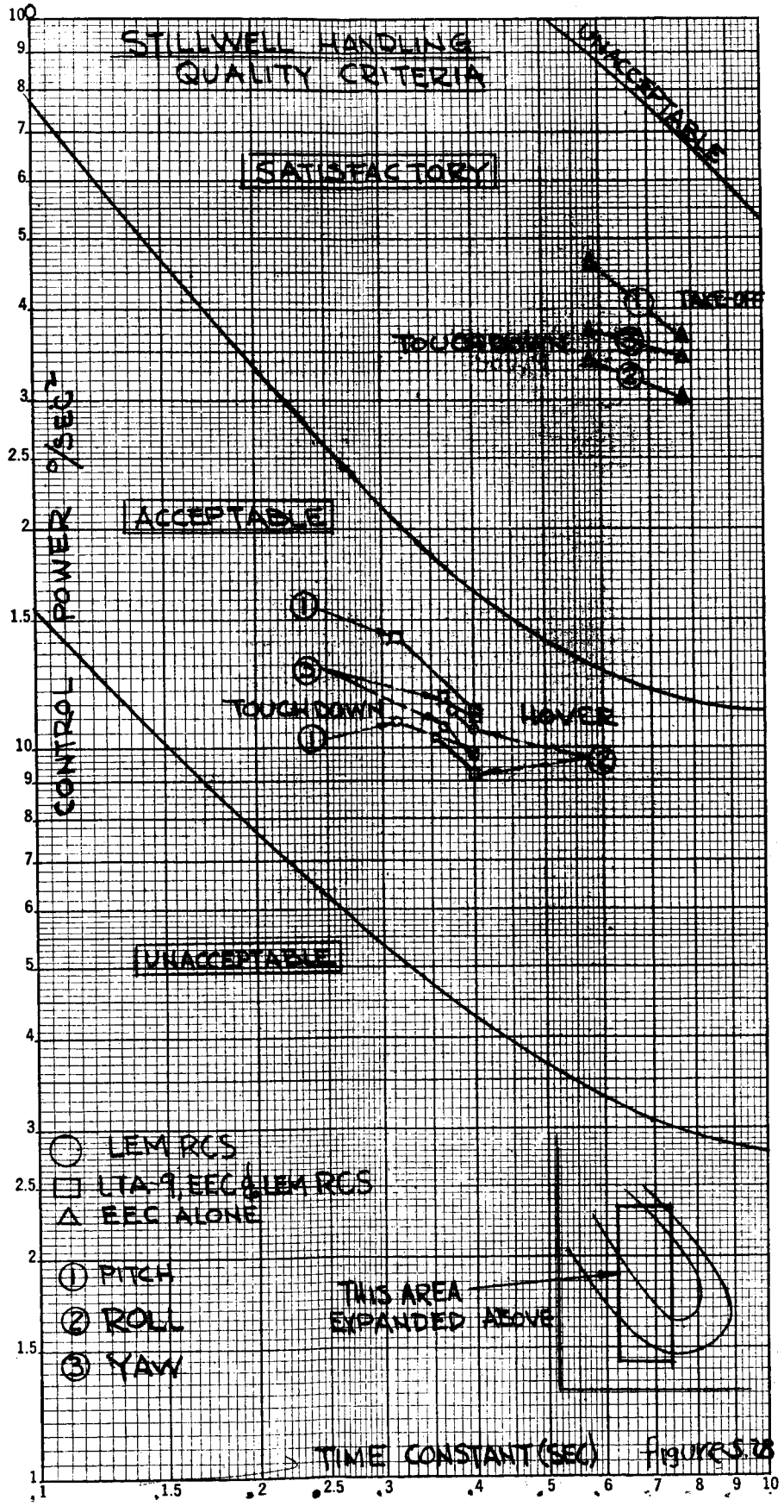


EEC Bleed-Air Reaction Control System Loop



LEM Reaction Control System Loop

Fig. 5.27 Bleed-Air and LEM Reaction Control Systems



Figures 5.28

Fig. 5.28

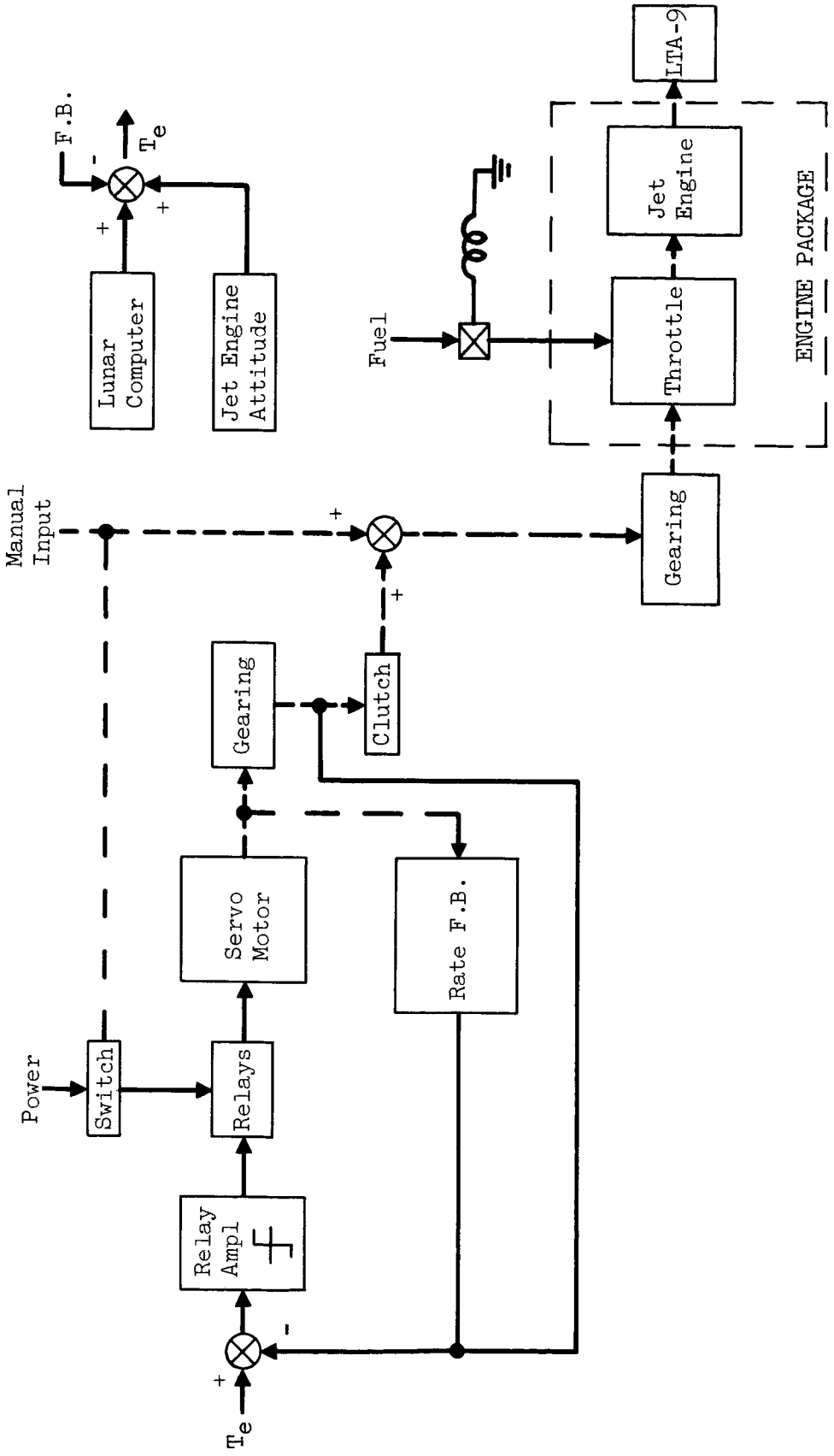


Fig. 5.29 Jet Engine Throttle Control Block Diagram

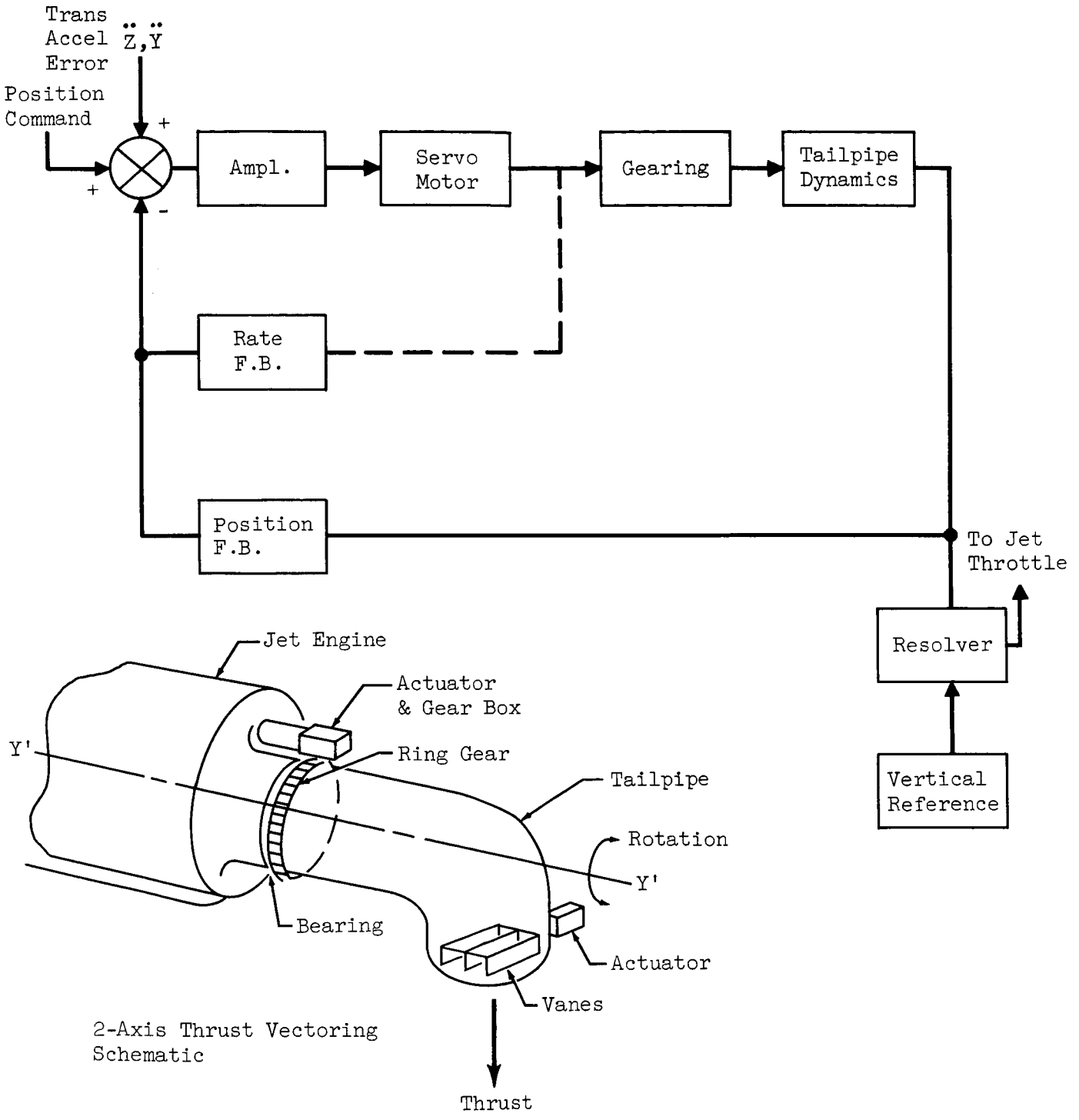


Fig. 5.30 Jet Thrust Vector Control Block Diagram

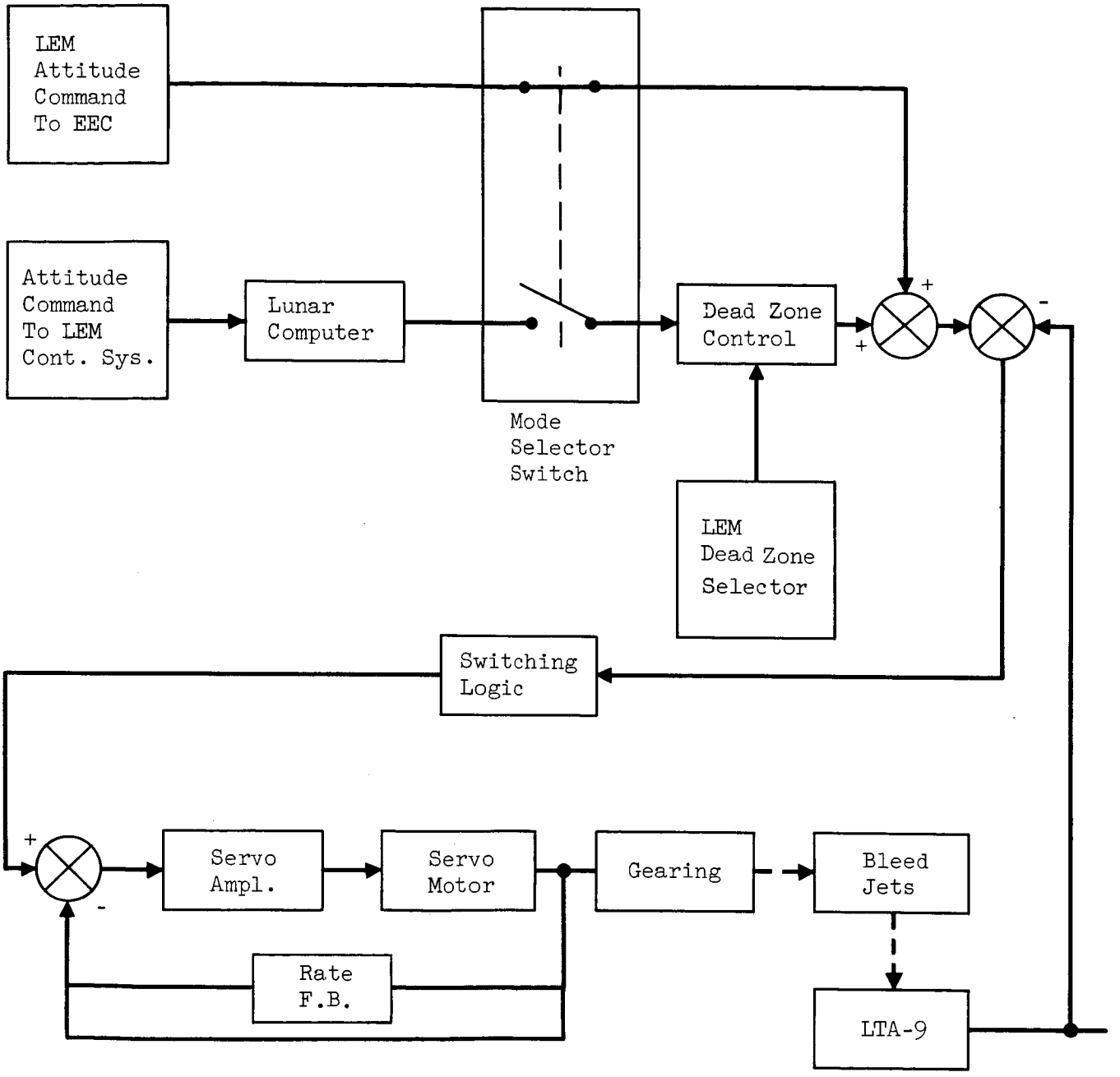


Fig. 5.31 Auxiliary Moment Control Block Diagram

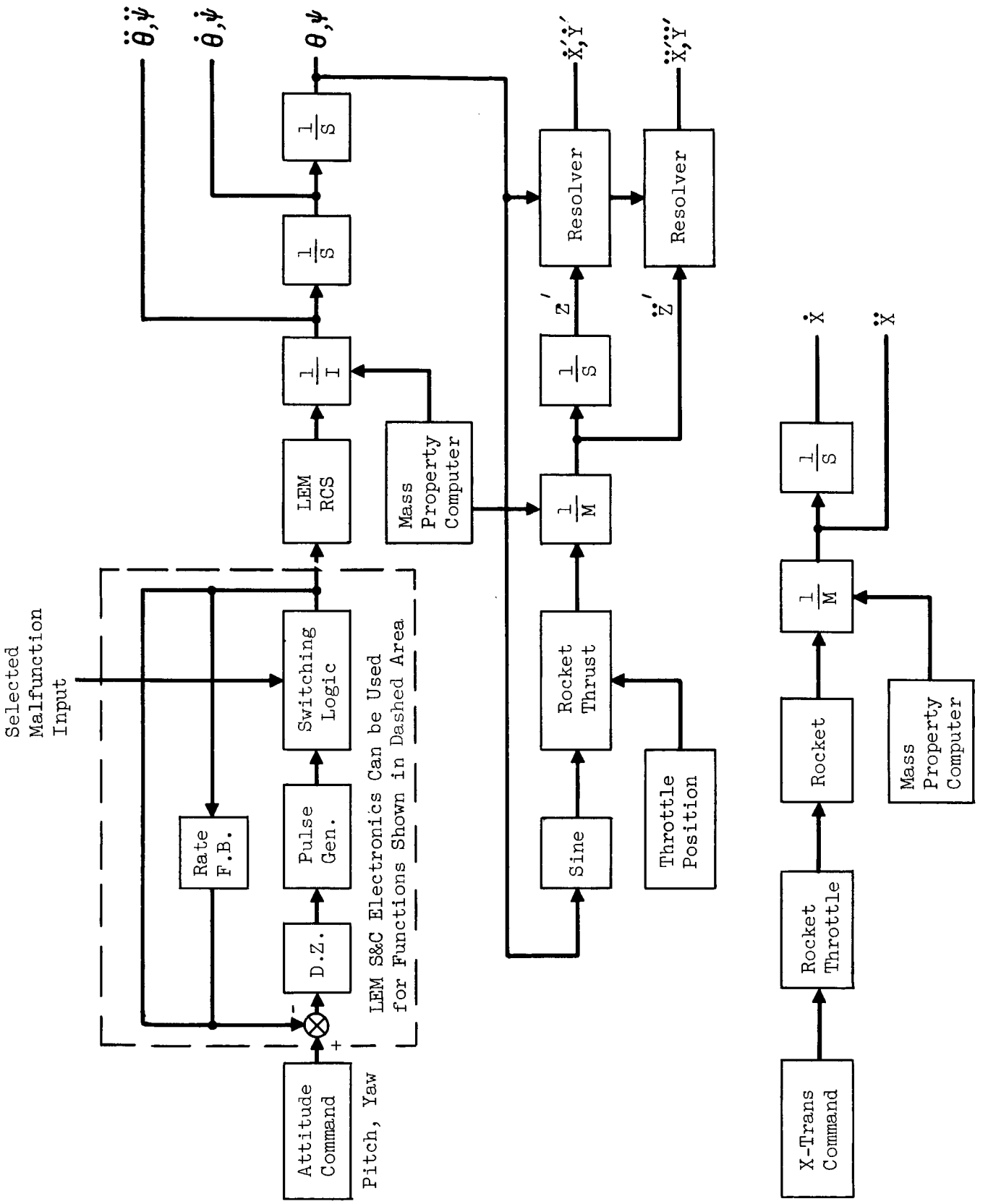


Fig. 5.32 Lunar Computer Block Diagram

6. LTA-9 CONFIGURATION STUDY

6.1 BASIC CONFIGURATION CRITERIA

The vehicle requirements discussed in section 3 establish design criteria which impose basic constraints on the general arrangements to be considered for the LTA-9 configuration. The more important of these criteria and their effect upon configuration design are briefly described below.

Three LTA-9 requirements exert an over-riding influence on selection of possible configurations. These are:

* Simulation of the lunar gravitational environment
* Stipulation of vehicle flight attitude extremes
* LEM center-of-gravity location and travel.

Use of the previously discussed "levitation" thrust to support five-sixths of the vehicle's weight arises from the lunar gravity simulation requirement. The resultant of the levitation thrust vector must of course act through the vehicle c.g. regardless of vehicle attitude to avoid induced pitching moments and must continually oppose the direction of the local gravity vector. Specification of maximum vehicle attitude excursions in pitch and yaw then defines the maximum thrust vectoring angles required to maintain verticality of the levitation thrust vector.

Center-of-gravity location defines the vector's desired point of application and rotation. Location of the LEM rocket engine on the vehicle X axis requires that the vector be split into parallel components symmetrically arranged about the axis. To avoid application of moments when the vehicle is pitched or yawed, the points of rotation of the individual components must lie in the vehicle Y-Z plane.

The above condition defines the vertical and fore-and-aft locations of a given levitation engine configuration. The lateral engine location is established by the maximum expected yaw excursion, which defines the outboard clearance required to avoid jet exhaust impingement on the lowest point of the vehicle structure.

Practically, c.g. shift in the vertical direction will always be present due to consumption of rocket propellant located below the vehicle center-of-gravity. Consequently, vertical location of the engine must "split the difference" between low and high c.g. positions to minimize the moments induced by vehicle angular excursions.

An additional consideration in levitation engine location is the avoidance of jet exhaust impingement on the vehicle landing gear for all possible thrust vector positions. Maintenance of LEM visibility and satisfactory provisions for engine intake-air are additional basic items which formed the basis for the following configuration studies.

6.2 PRELIMINARY CONFIGURATION STUDIES

The LTA-9 configuration study started with an exploratory phase in which all the VTOL turbojet propulsion systems summarized in table 5.2.1 were evaluated in terms of LEM-Levitation system configuration compatibility. For the purposes of these preliminary configuration studies the following guidelines were utilized in each LTA-9 general arrangement:

* Pilot Safety
* Jet Engine Performance
* Engine-out Capability
* Gyroscopic Coupling
* Weight
* Degree of structural modification to the basic LEM
* Pilot's Field of Vision

These considerations were also applicable in evaluating the subsequent detailed configurations. As the study progressed, design complexity and in-the-field maintainability became factors of design feasibility.

The number of jet engines in any specific configuration included single jet, dual, four, five and six jet installations. As mentioned earlier (under propulsion section 5.3.3) a rocket levitation system is impractical; however, all-rocket LTA-9 configurations using a modified LEM descent engine were considered.

Table 6-1 lists the applicable turbojet engine types and number of each type required to support an LTA-9.

TABLE 6-1

No. of Engines	Designation	Manufacturer
1	BS 53/5	Bristol-Siddeley
2	BS 59/7	Bristol-Siddeley
4	CF 700-2B	General Electric
4	RB 162	Rolls Royce
5	SJ-132	General Electric
6	SJ-132	General Electric
6	JT12A-6	Pratt and Whitney

Each configuration is identified by its levitation powerplant designation, prefixed by a sequential number indicating the specific arrangement. For example, (11) SJ-132, refers to the eleventh LTA-9 configuration using SJ-132 turbojets.

6.2.1 Results of the Preliminary Configuration Study

Analysis of all the preliminary configurations (approximately 25) permitted a comparison of the merits and limitations of each approach. In turn, this review shaped the course of the subsequent detailed configuration studies. The configuration comparison made it evident that levitation engine gimballing would necessitate; hydraulic actuation to position the engine (weight) within the desired response times, flexible or swivelled fuel lines, swivelled bleed

air ducts, and heavy gimbal rings and support structure. Thrust vectoring the jet engines using electromechanically actuated swivelled nozzles and tailpipe vanes offers a less complex and lighter arrangement. Furthermore, it became apparent that gyroscopic effects could be minimized by proper positions of the tubrojets. The exploratory studies also indicated that the basic five point LEM landing gear would require modification to avoid jet blast impingement, allow a symmetric engine installation and maintain the desired LTA-9 inertial properties.

In reviewing specific configurations certain design features and design criteria became obvious. The Bristol-Siddeley BS 53/5 permitted a single-engine levitation system; however, its installation would require a complete redesign or the LEM descent stage and relocation of the LEM descent rocket engine. Radial positioning of multi-engine configurations (i.e. 4, 5, or 6 equal spaces) resulted in complex installations with the pilot's vision impaired in some cases. More desirable LTA-9 arrangements, are illustrated in figure 6-1 through 6-7.

Configuration: (2) BE 59/7 - figure 6-1 illustrates an arrangement with two levitation engines, vertically mounted on the LEM descent stage. The engines are double gimballed about the LEM's c.g. The gimbal installation is designed for ± 30° pitch excursion and ± 15° in yaw

The prime limitations of this configuration are strong gyroscopic coupling and lack of engine-out capability.

Configuration: (3) CF 700-2B - As shown in figure 6-2 the four vertically mounted turbofans are arranged symmetrically in pairs about the Z-Z axis. The engines are double gimballed and mounted on the descent stage.

Gyroscopic torques are minimized by the contra-rotating components of the CF 700-2B. However, the bleed air required for vehicle trim power results in excessive loss in thrust, nominally, an 18% thrust degradation for 8 lb./sec. bleed air.

Configuration: (4) CF 200-2B - This arrangement, figure 6-3, is identical to configuration (3) CF 700-2B except that the engines are single gimballed about the LEM Y-Y axis and rely on actuated tailpipe vanes for thrust vectoring about the Z-Z axis.

Gimbal complexity is reduced and a net weight savings results. The commentary of configuration (3) CF 700-2B is also applicable to this arrangement.

Configuration: (5) SJ 132 - The six engine configuration depicted in figure 6-4 employs three double gimballed engines mounted vertically on each side of the descent stage. Engine out capability is provided. Gyroscopic effects are minimized (engine spin vectors remain essentially vertical during vehicle attitude changes). Gimbal complexity and weight, however, are significant.

6.3 DETAILED CONFIGURATION STUDIES

Further study effort was expanded in three approaches, two of which were six-engined SJ-132 configurations, the third a four engined CF 700-2B arrangement.

For these three conceptual designs, weight, balance and mass properties were determined. A stress analysis was made from which structural member weight could be estimated.

The design criteria for these detailed configurations were based upon:

* Maximum Pitch Angle	$\pm 30^{\circ}$
* Maximum Yaw Angle	$\pm 15^{\circ}$
* Maximum Stress (Ultimate)	1.5 x limit load.
* Landing Conditions	
Maximum gross weight	10800 lbs.
Maximum vertical rate	10 fps
Maximum horizontal rate	5 fps
Maximum pitch angle	5°

The conditions which were critical for structural design were landing loads and engine support structural loads. Maneuvering loads were not a factor in structural design.

Landing Load Conditions

1. Vertical Landing on four wheels at 10 fps
2. Incipient tipping of vehicle due to braking load

Engine Support Load Conditions

1. Full engine thrust directed parallel to X-X axis
2. Full engine thrust directed $\pm 15^{\circ}$ to X-Z plane
3. Full engine thrust directed $\pm 30^{\circ}$ to X-Y plane
4. Vertical landing on four wheels at 10 fps.

The following sections discuss and compare the specific design features of each of the three configurations investigated in detail.

6.3.1 (11) SJ 132 Horizontal Configuration

This configuration, shown in figure 6-5 utilizes six SJ-132 engines each rated at 3040 lbs. thrust (S.L. standard day) which are mounted horizontally on the LEM descent stage, three on either side of the Z-Z axis. The spin axis plane of the turbojets is coincident with the c.g. of the vehicle on the Y-Y axis. Thrust vectoring is accomplished by swiveling the engine nozzles $\pm 30^{\circ}$ about the Y-Y axis and actuating a set of vanes, mounted in the tailpipe of each nozzle, $\pm 15^{\circ}$ about the Z-Z axis. Air is supplied to the six engine inlets from a common plenum chamber located aft of the crew compartment. The jet fuel tank is mounted in the plenum chamber, concentric with the X-X axis on the vehicle nominal c.g. Turbojet bleed-air reaction control jets, on the axis parallel to the Y-Y LEM axis are mounted off the levitation engine support structure. The two fore and aft bleed air reaction jets are mounted off the ascent stage, similar to the manner in which the basic LEM RCS nozzles are installed. The crew compartment is modified by

addition of two zero-zero ejection seats, and structural bulkhead for their support, and two overhead hatches for ejection. The docking tunnel is omitted since it is not required for the training mission.

All thrust and landing load components produced by the engine-tailpipe assembly parallel to the X-Y plane are balanced by truss frames parallel to that plane. Load components parallel to the Z-Z axis are balanced by the outer frames inclined to the Y-Y axis. The yoke assembly transmits the thrust and landing loads to the truss frames. Additional stiffeners are required on the upper and lower surfaces of the descent stage where the frames parallel to the X-Y plane join them. These stiffening members balance the thrust components parallel to the X-X axis introduced by the frames to the planes of the upper and lower skins. (The stiffeners are also used in configuration (13) SJ 132, discussed in Section 6.3.2).

Each wheel of the modified or "work horse" landing gear is attached to the descent stage with tubular struts. The upper attachment points are coincident with attachment points in the engine support structure. The landing gear is supported at two points by three triangular trusses connecting these points to the descent stage.

The horizontal, opposed engine arrangement cancels engine-vehicle gyroscopic effects and results in only a slight weight penalty when compared with six vertically mounted engines, configuration (13) SJ 132.

A comparison of LTA-9 and LEM mass properties for this configuration is presented in table 6-3. A detailed derivation of the weight and balance for configuration (11) SJ-132 is shown in table 6-4. Center of gravity travel in the Y direction is negligible. The undesirable LTA-9 c.g. shift in the X and Z directions relative to the c.g. location of the LEM (table 6-3) can be compensated for by differential levitation jet throttling.

This approach, however, reduces the thrust available to cope with engine-out conditions.

A detailed preliminary design effort would effect a substantial reduction in the c.g. travel indicated for the conceptual designs presented here. As an example, a brief study conducted on the (11) SJ-132 configuration indicates that by: relocating rocket propellant symmetrically about the X axis; relocating the jet fuel tank in the positive X direction; and adding 560 pounds of ballast at the aft end of the vehicle; the improved center of gravity characteristics shown below (table 6-2) are obtained.

TABLE 6-2

	Weight	X	Z
Start	11,108	213.8	0
Start of descent	10,496	210.6	0
Landing	8,280	214.0	.2
Dry	8,213	213.7	.2

A similar but more efficient approach emphasizing weight reductions and relocations rather than additions of ballast would be implemented in a

detailed preliminary design phase. Also during this phase, the match in inertias could be improved. Inertia match is less critical than c.g. match, since the EEC system provides the difference in angular accelerations required to match LEM characteristics.

Table 6-3

MASS PROPERTIES COMPARISONS

(11) SJ-132 CONFIGURATION

		WEIGHT (lbs.)	X(in.)	Z(in.)	I_x(SF^2)	I_y(SF^2)	I_z(SF^2)
Start	(LTA-9)	10407	205.6	1.4	7604	5857	6370
Hover	(LTA-9)	9771	204.1	1.5	7581	5765	6278
Touchdown	(LTA-9)	7723	212.0	5.6	6636	4229	5600
Hover	(LEM)	10843	214.8	1.9	6001	6351	6482
Touchdown	(LEM)	10016	218.0	2.2	5559	5805	5950

NOTE: All items are assumed symmetrical about the X-Z plane.

		I_x	I_y	I_z
Percentage difference of mass properties of LTA-9 with respect to LEM	Hover	+26	-9	-3
	Touchdown	+16	-27	-6

		X	Z
LTA-9 C.G. location with respect to LEM C.G. (in inches)	Hover	-10.7	-.4
	Touchdown	- 6	-3.4

Table 6-4

LTA-9 - CONFIGURATION (11) SJ-132

DERIVATION OF WEIGHT AND BALANCE

	WEIGHT (lbs.)	X(in.)	Z(in.)
Stripped LEM	4767.4	210.1	9.2
Remove:			
Top of Engine Compartment	-20	285	
Add:			
Engine Trusses	104	194	
Exhaust Nozzles	132	212	

(Cont'd)

Yoke Assembly	180	214	
Bearings	40	214	
Vanes	62	205	
Engines	1830	214	
Jet Fuel Tank	55	224	
Jet Fuel Plumbing & Pump	65	206	
Cabin Pressurization	50	235	15
Levitation Reaction System	(213)	(237)	(-)
Thrust Chambers & Supports	60	234	
Ducting & Plenum	113	240	
Valves, Actuators, & Linkage	40	235	
EEC Actuators & Linkage	96	214	
EEC Electronics	40	240	-64
Throttle Servos	12	214	
EEC Controls	26	242	47
Total Dry LTA-9	7652.4	212.0	5.6
Add:			
Jet Fuel	1045	220.4	--
Rocket Fuel	558	167	46.5
Rocket Oxidizer	1116	166	-47
Reaction Control Propellant	35.2	216.3	-51
Total Full LTA-9	10406.6	205.6	1.4

6.3.2 (13) SJ 132 Vertical Configuration

This configuration, illustrated in figure 6-6, utilizes six vertically mounted SJ-132 engines located symmetrically with respect to the X-Z plane in two clusters of three engines each. The c.g. of each engine package is located in the X-Y plane.

Straight-through skew axis vectoring is required for this configuration. The engines' vertical location is dictated by the requirement to place the theoretical point of rotation of the thrust vectors in the horizontal plane through the nominal c.g. The engines are mounted approximately three feet outboard of the vehicle plan form to prevent jet exhaust impingement on the structure at maximum yaw attitude. Thrust loads are taken out by members attached to the main engine support points. Struts running from engine hardpoints to the main assembly prevent transmission of forces to the engine shell structure. The truss frames parallel to the X-Y plane sustain load components parallel to that plane. Two planes of "K"-bracing balance load components parallel to the Z-Z axis. Since the yoke does not transmit the main force components, it it comparatively lightweight.

The vertical orientation of the engines causes application of gyroscopic couples to the vehicle during angular motion about the Y and/or Z axes. The magnitude of the moment increases linearly with angular rate and approaches

1750 foot pounds at a pitch or yaw rate of 20 degrees per second.

The mass properties of this LTA-9 configuration are compared to the LEM in table 6-5. The weight of this vehicle is slightly lighter than the horizontally opposed SJ-132 configuration discussed earlier. Inertias about the X and Z axes are appreciably higher (15 and 27% respectively) than those of the (11) SJ-132 engine due to the outboard location of the engines. Center of gravity match with the LEM is closer in the X direction and substantially the same in the Z direction. A more detailed derivation of the weights and balances for this configuration is shown in table 6-6.

Table 6-5

LTA-9

MASS PROPERTIES COMPARISON

(13) SJ-132 Configuration

	Weight(lbs.)	X(in.)	Z(in.)	$I_x(SF^2)$	$I_y(SF^2)$	$I_z(SF^2)$
Start (LTA-9)	10321	211.0	1.4	8760	6378	8066
Hover (LTA-9)	9697	210.0	1.5	8737	6319	8007
Touchdown (LTA-9)	7657	219.5	5.6	7792	4568	7115
Hover (LEM)	10843	214.8	1.9	6001	6351	6482
Touchdown (LEM)	10016	218.0	2.2	5559	5805	5950

NOTE: All items are assumed symmetrical about the X Z plane

Table 6-6

LTA-9 - CONFIGURATION (13) SJ-132

DERIVATION OF WEIGHT AND BALANCE

	Weight (lbs.)	X (in.)	Z (in.)
Stripped LEM	4767.4	210.1	9.2
Add:			
Engine Trusses	236	221	
Exhaust Nozzles	58	217	
Yoke Assy.	50	222	
Bearings	38	222	
Vanes	32	216	
Engines	1830	242	
Jet Fuel Tank	55	224	
Jet Fuel Plumbing & Pump	85	219	
Cabin Pressurization	50	235	15
Levitation Reaction Sys.	(213)	(237)	
Thrust Chambers & Supports	60	234	

(Cont'd)

Ducting & Plenum	113	240	
Valves, Actuators & Linkage	40	235	
EEC Actuators & Linkage	96	222	
EEC Electronics	40	240	-64
Throttle Servos	12	214	
EEC Controls	26	242	47
Total Dry LTA-9	7588.4	219.6	5.7
Add:			
Jet Fuel	1023	220.4	
Rocket Fuel	558	167	46.5
Rocket Oxidizer	1116	166	-47
Reaction Control Propellant	35.2	216.3	-51
Total Full LTA-9	10320.6	211.0	1.4

6.3.3 (7) CF700-2B Vertical Configuration

Figure 6-6 indicates a configuration employing four CF700-2B engines, each rated at 4200 lb. thrust (S.L., standard day). The vertical mounted engines are arranged in pairs on each side of the Z-Z axis and mounted off the descent stage. Again, as in configuration (13) SJ-132 a plenum chamber is not required. The design utilizes skew axis thrust vectoring as described in Section 5.3.2. The turbofan's countra-rotating turbine and fan minimize the gyroscopic problems associated with the vertical engine installation of (13) SJ-132.

The vehicle general arrangement is identical with configuration (11) SJ-132 with the exception of the engine installation. A yoke is bolted to the engines at their main attachment points; the yoke and descent stage are connected by a truss. A segment of the descent stage is removed to avoid jet engine exhaust impingement on the structure.

Since the engines in this configuration are mounted vertically outboard of the descent stage as in configuration (13) SJ-132, a similar structural configuration is used to support the engines. The truss members are modified to withstand the force components parallel to the Z-Y plane efficiently. Additional members are required to support the upper portions of the engines because of the heavy engine component weight in this area. These members are parallel to the Z-Y plane and carry loads between hard points on the engines and the ascent stage. Two yokes are required in this configuration; one to transmit loads from the main engine support point to the main trusses and one at the exhaust nozzle bearings.

The upper and lower skins of the descent stage are reinforced in a similar method to that used in the SJ-132 configurations. However, additional center truss stiffeners are not necessary, since a main radial stiffener exists at this section.

The gross weight of this configuration exceeded that of the SJ-132 configurations by 5%. A derivation of the weights and balances for this configuration is given in table 6-7.

6.3.4 All-Rocket Configuration

The all-rocket LTA-9 configuration shown in figure 6.8 utilizes a LEM type descent engine modified for atmospheric operation and a descent stage that closely resembles the basic LEM. The degraded rocket performance resulting from atmospheric operations results in a higher propellant demand. The need for maintaining limited c.g. shift as propellant is expended also makes it desirable to distribute expendables symmetrically about the c.g. therefore, partial loading of all six LEM descent stage propellant tanks is employed. The absence of bleed air reaction controls also results in less departure from the basic LEM configuration.

The landing gear modifications and the crew compartment alterations however, will be similar to the jet levitation conceptual configurations discussed in sections 6.3.1 through 6.3.3

TABLE 6-7

LTA-9 - Configuration (7) CF700-2B

DERIVATION OF WEIGHT AND BALANCE

	Weight (lbs.)	X (in.)	Z (in.)
Stripped LEM	4767.4	210.1	9.2
Add:			
Engine Trusses	256	216	
Exhaust Nozzles	68	217	
Yoke Assy.	106	245	
Bearings	52	222	
Vanes	42	217	
Engines	2460	255	
Jet Fuel Tank	46	214	
Jet Fuel Plumbing and Pump	65	223	
Cabin Pressurization	50	235	15
Levitation Reaction System	(213)	(237)	(-)
Thrust Chambers and Supports	60	234	
Ducting and Plenum	113	240	
Valves, Actuators, and Linkage	40	235	
EEC Actuators and Linkage	96	220	
EEC Electronics	40	240	-64
Throttle Servos	12	214	
EEC Controls	26	242	47
Total Dry LTA-9	8299.4	225.6	5.2
Add:			
Jet Fuel	704	214	-
Rocket Fuel	587	168	46.5
Rocket Oxidizer	1173	167	-47
Reaction Control Propellant	35.2	216.3	-51
Total Full LTA-9	10798.6	215.3	1.2

TABLE 6-8
LTA-9 ALL ROCKET CONFIGURATION

DERIVATION OF WEIGHT AND BALANCE

	Weight (lbs.)	X (in.)	Z (in.)
Stripped LEM	4767.4	210.1	9.2
Remove:			
Descent Engine (w/skirt removed)	-184.7	191	
Add:			
"Boiler plate" Descent Engine (higher thrust)	300	176	
Four Descent Propellant Tanks and Plumbing	226	175	3.8
Cabin Pressurization	50	235	15
Total Dry LTA-9	5158.7	207.5	8.8
Add:			
* Rocket Fuel	953	166	
* Rocket Oxidizer	1907	165	
Reaction Control Propellant	35.2	216.3	-51
Total Full LTA-9	8053.9	192.6	5.4

* Rocket propellant weight based on "NASA Project Apollo Working Paper 1045", Appendix H. (See page 5-14 of this report).

A weight and balance derivation for an all rocket LTA-9 configuration is presented in table 6-8. This breakdown is based on a mission profile similar to that described in NASA Working Paper 1045, Appendix H; i.e., climbout to 300 feet, followed by a 30 second hover, a descent to 15 feet at 10 fps and a touchdown at 3 fps. Should the all-rocket hover altitude be altered as shown in figure 5-10, the mass and balance properties will change accordingly.

6.3.5 Configuration Comparison and Evaluation

Each of the detailed configurations was evaluated in accordance with the guidelines set forth in Section 6.2. The all-rocket configuration is unique and will not be compared with the jet levitation conceptual designs in detail. Outstanding differences are: less modification required, more extensive rocket engine development, sharply reduced mission time for a given weight, and no simulation of lunar handling characteristics. While each configuration had adequate engine performance for the LTA-9 mission profile (figure 8-1), the 4 engine CF700-2B configuration does not provide engine-out safety. The SJ 132 configurations have the potential for engine-out performance and provide sufficient bleed air for the LTA-9 reaction control subsystem.

Gyroscopic moments are evident in the vertically mounted SJ-132 configuration. Gyroscopics are minimized, if not completely eliminated, in the countra-rotating CF700-2B turbofan configuration; on the other hand, the gyroscopic moments are cancelled with the horizontally opposed SJ-132 configuration.

Thrust vectoring by rotating jet nozzles and tailpipe vanes results in lightweight, highly responsive electromechanical actuation, as opposed to heavier hydraulic actuators required for gimballing complete engines. However, the rotating nozzle pitch axis and the tailpipe vane (LEM) roll axis center's of rotation are slightly offset. With the skew axis vectoring technique of configuration (7) CF200-2B this consideration is eliminated.

The plenum chamber jet inlet system in the six SJ-132 horizontal opposed engines arrangement design will provide equal and adequate air to each engine throughout the LTA-9 angle of attack (and sideslip) range. The relatively low flight speeds, less than 100 fps, ease the plenum chamber design requirement.

On the basis of estimated gross weights the horizontal SJ-132 configuration is 86 lbs. heavier than the 10381 lb. configuration (13) SJ-132, while configuration (7) CF 200-2B is 478 lbs. heavier than the (13) SJ-132. Preliminary analysis has shown that a practical solution to maintaining the LEM c.g. position (especially in the vertical and fore and aft directions) can be attained by repositioning of onboard equipment and expendables.

From the standpoint of pilot safety, each of the three detailed configurations would be equipped with rocket ejection seats. Engine out capabilities were cited earlier. As a precautionary measure, vehicle sized parachute recovery systems could be installed in each configuration, however, the heavy weight (7) CF 700-2B vehicle is least conducive to carrying such a system. Vehicle parachute recovery is discussed further, in Section 8.4.

The pilot's field of vision is not impaired by arrangement of engines or landing gears in any of the three detailed configurations.

The structural modifications to the basic LEM structural arrangement amount to redesign of local areas. This includes strengthening the descent stage for levitation propulsion and bleed air reaction control, and modification of the landing gear. The ascent stage changes include the addition of ejection seats and changes in hatches. The cut-back LEM descent nozzle will require the installation of a titanium liner to protect the structure adjacent to the rocket exhaust. This heat shield will be separated from the primary structure using (Min-K) insulation blocks. The level of structural modification for each of the detailed configurations is of the same order of magnitude.

Based on the preliminary wind tunnel testing, described in section 4.2, some modification of LTA-9 external contours is expected (to minimize flow separation and buffeting). These modifications will be accomplished by the addition of secondary structure in the form of fairings and fillets.

6.3.6 Conclusion

The (11) SJ-132 configuration was selected as the conceptual design most representative of a feasible approach for the following reasons:

(1) The (7) CF 700 2B configuration is marginal in thrust (see page 5-23); is the heaviest configuration; has the greatest vertical c.g. shift; and does not possess engine out capability. It was therefore considered to be unsuitable.

(2) The configurations using the SJ-132 engine have generally similar characteristics, with the vertical engine configuration having a slight edge in the areas of weight, vertical c.g. travel closer to that of LEM, and installation simplicity. Both configurations have engine out thrust and bleed-air moment capability and adequate take-off thrust. The (11) SJ-132 configuration is the sole choice, however, which provides adequate thrust and does not present adverse gyroscopic characteristics. This configuration was therefore chosen as the representative design on which to base an LTA-9 development program and budgetary cost estimate.

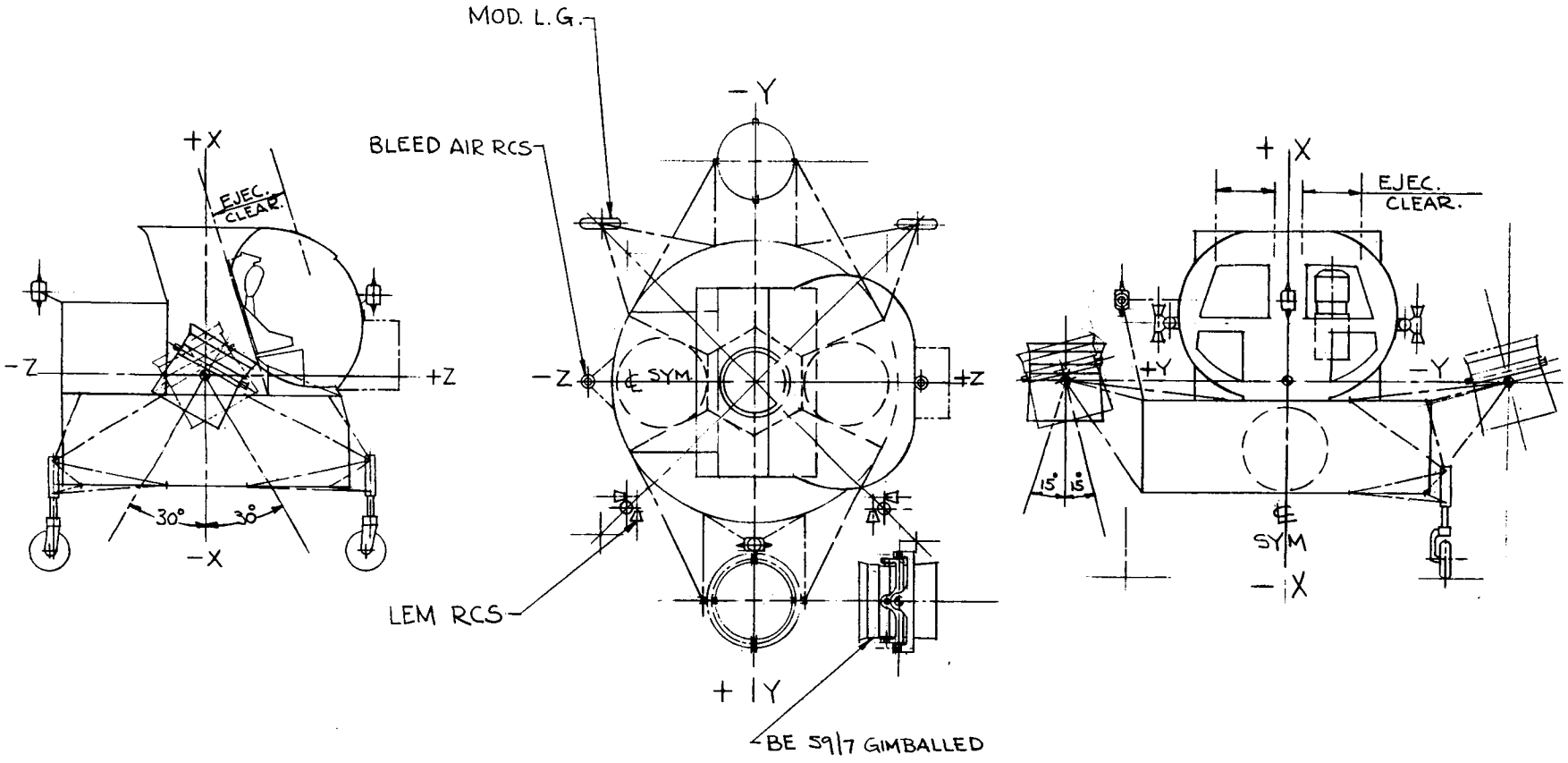


Fig. 6.1- 2 Gimballed BE 59/7 Engines, Conf. (2) BE 59/7

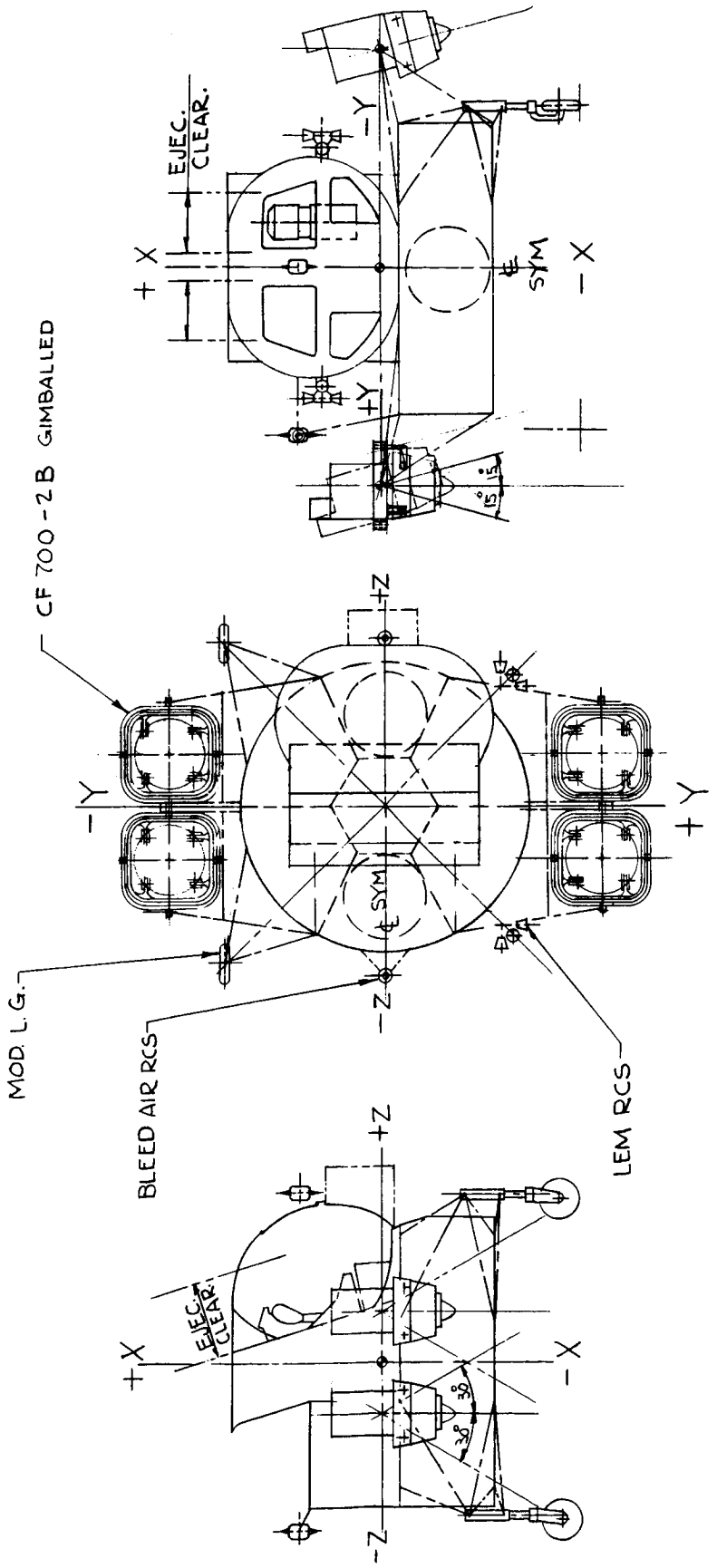


Fig. 6.2- 4 Gimballed CF 700-2B Engines, Conf. (3) CF 700-2B

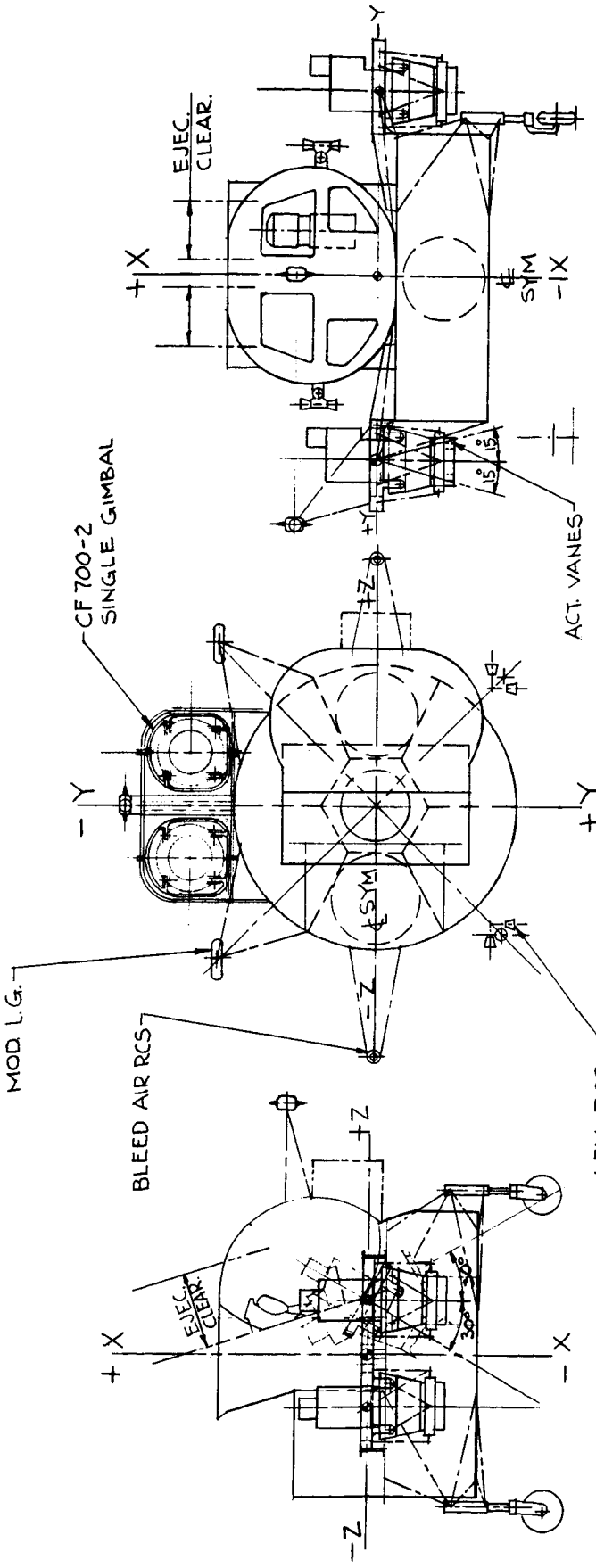


Fig. 6.3- 4 CF 700-2B Engines Single-Gimballed and Thrust-Vectored, Conf. (4) CF 700-2B

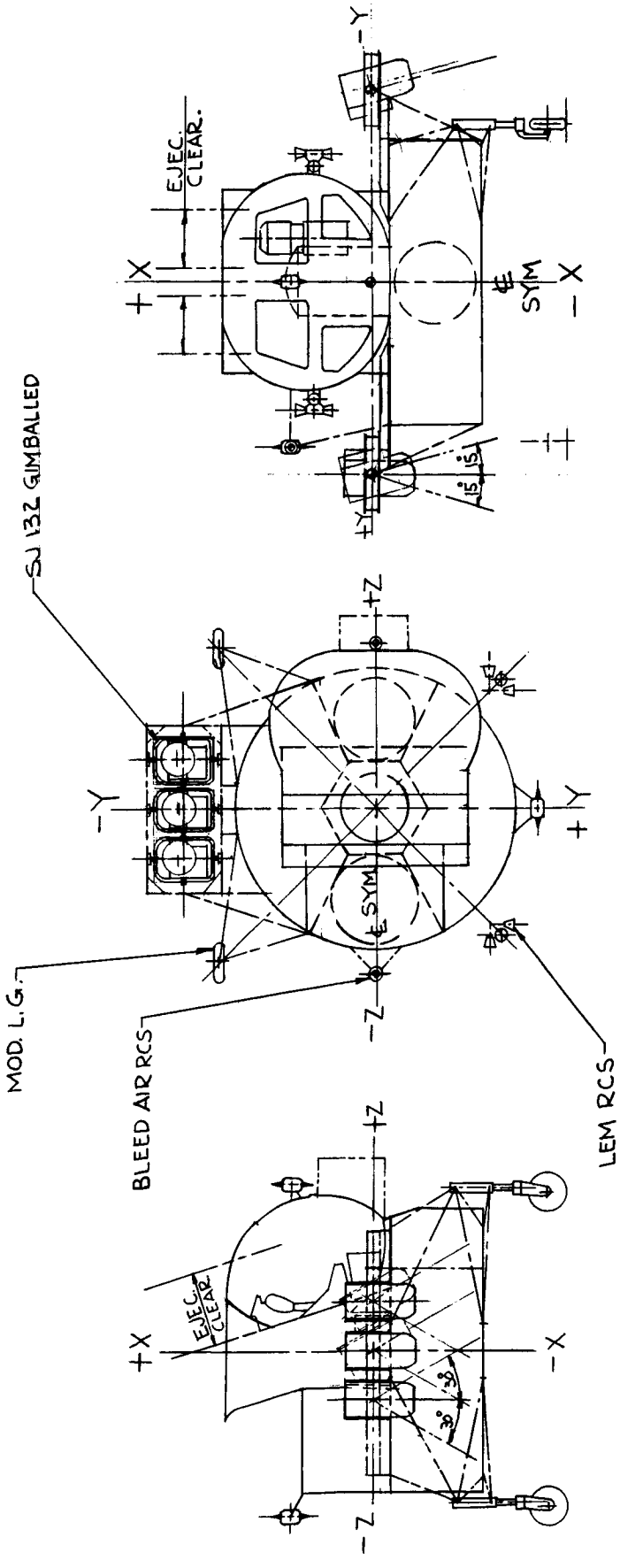


Fig. 6.4- LTA-9 6-Gimballed SJ 132 Engines, Conf. (5) SJ 132

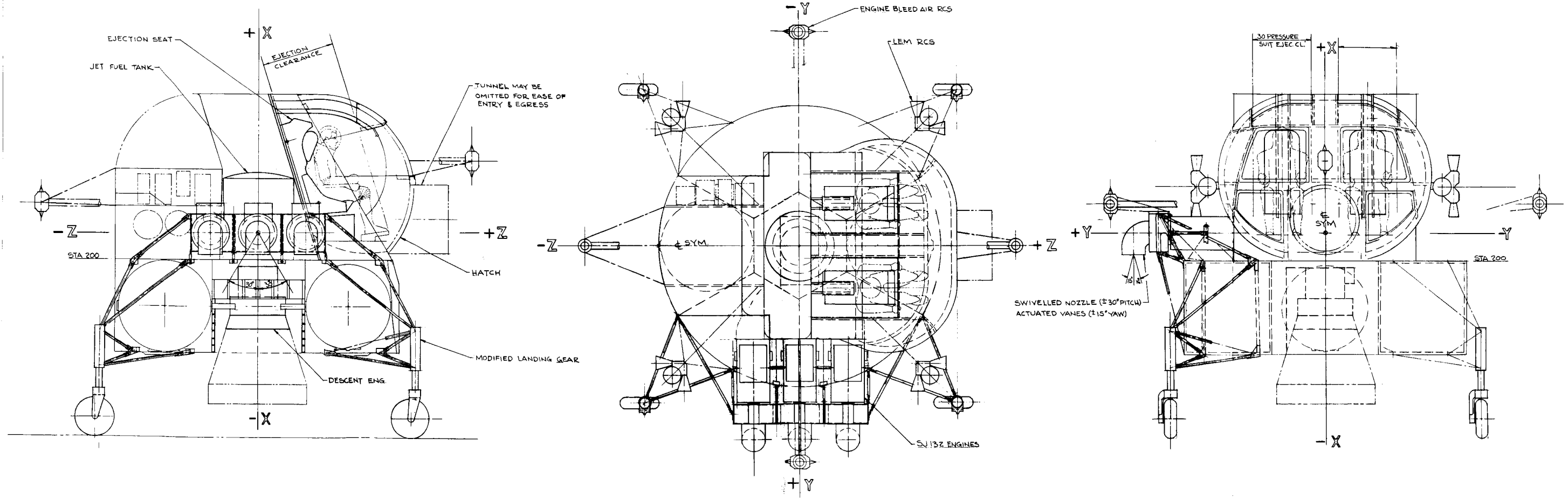


Fig. 6.5- LTA-9 Configuration (11) SJ 132, 6 Thrust-Vectored SJ 132 Engines. Horizontal

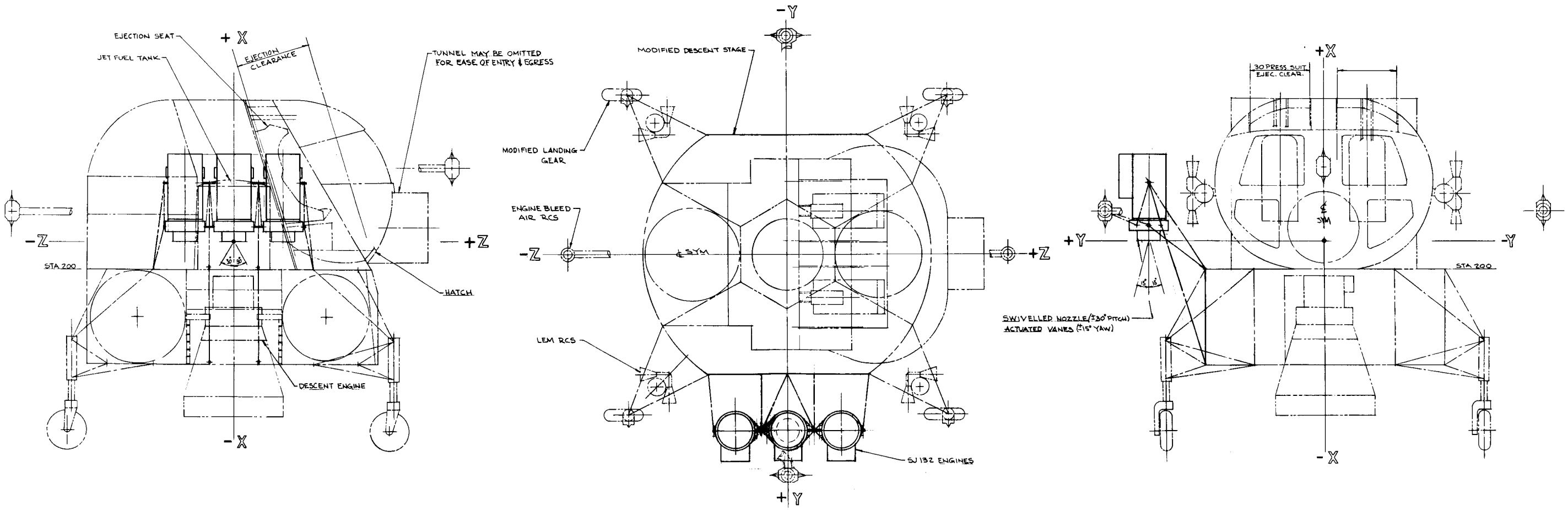


Fig. 6.6- LTA-9 Configuration (13) SJ 132, 6 Thrust-Vectored SJ 132 Engines. Vertical

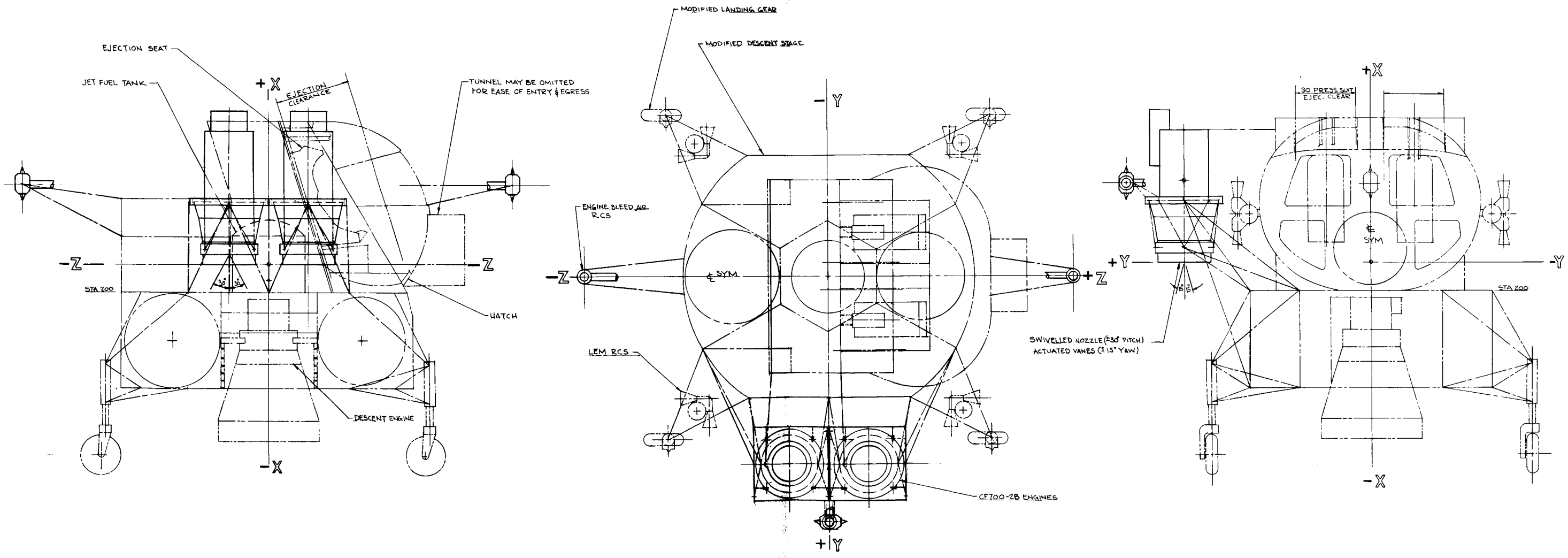


Fig. 6.7- LTA-9 Configuration (7) CF 700-2B 4 Thrust-Vectored CF 700-2B Engines. Vertical

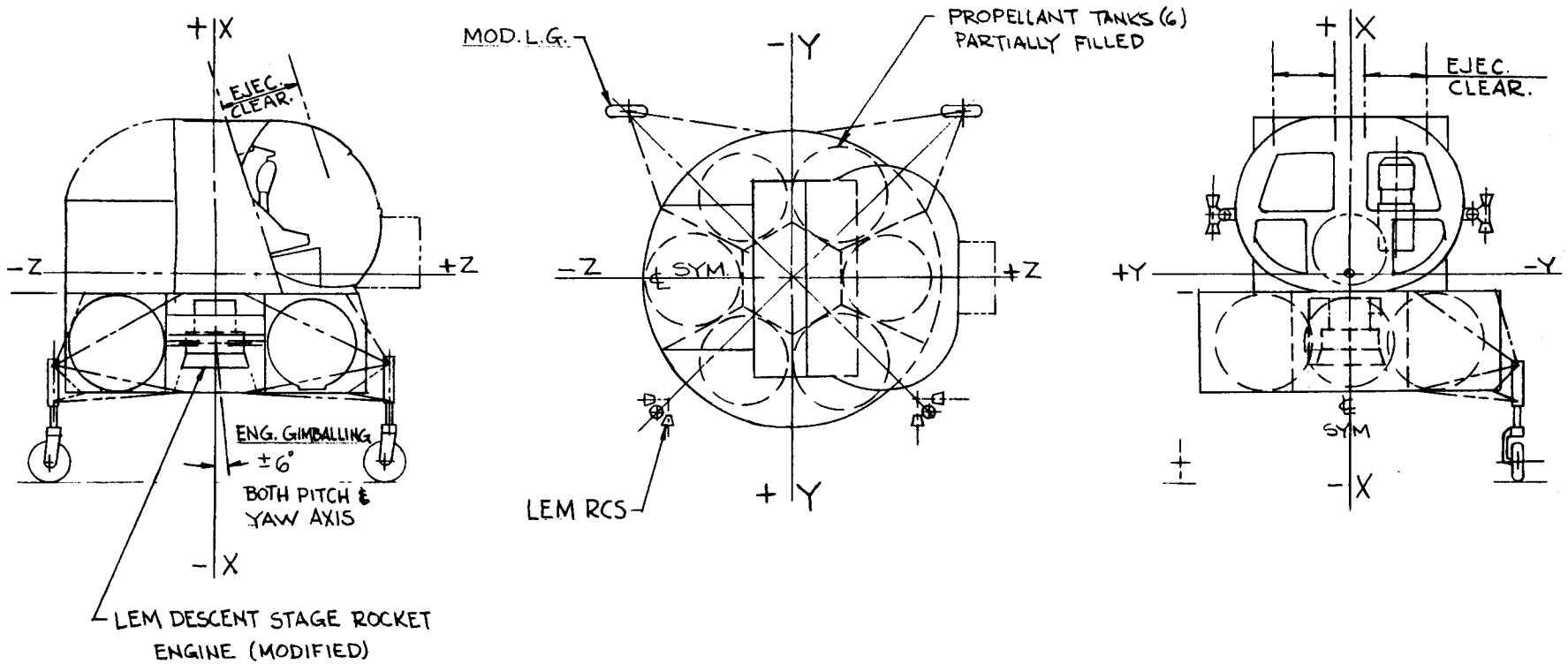


Fig. 6.8- LTA-9 All-Rocket Engine Configuration (Modified Descent Engine)

7. LTA-9 DEVELOPMENT TEST PROGRAM

7.1 DEVELOPMENT APPROACH

The ultimate goal of atmospheric free-flight training and operations is to insure a safe manned lunar landing and return. The objective of the LTA-9 ground and flight test program is to guarantee, in advance of LTA-9 usage by the LEM astronauts, the completely safe and successful performance of terminal descent operations.

In order to optimize the use of time and resources available to accomplish this task, a test program well integrated and properly phased with the LEM ground and flight tests is described. Figure 7.1 summarizes the development test program and illustrates the major scheduling milestones, phases and tie-in to the basic LEM program. The test program commences with detail design go-ahead. These initial tests, called out in figure 7.1 under Ground Testing - Subsystems, include: development, design feasibility, design verification, and subsystem qualification tests. The environmental qualification of LTA-9 is accomplished through a proof-test program using No. 1 vehicle. The tests will be integrated with the results of the LEM drop test, structural test, and ECS tests (LTA-2, LTA-3, TM-2 respectively). Prior to operational usage in the LEM terminal descent training program, a flight test program will confirm the ability of design and construction features to function properly under actual operating conditions. The flight test program is initiated in mid-1965 at Grumman's Long Island facilities and is completed at the end of 1966 at WSMR.

Two fully qualified flight training LTA-9 vehicles will be available to the NASA at WSMR on 1 January 1967. At delivery, these vehicles will be identical to each other with the exception of their alighting gear. One vehicle will employ a five-pad gear simulating the LEM tipover-restoring moments; the other vehicle will be equipped with a more conventional helicopter-type, wheeled, landing gear. Probably, both vehicles could have helicopter type gear initially with provisions for changing to five-pad gear. The vehicles will have the capability of changing alighting gear to serve the best interests of the training program.

This development program will provide the astronauts with a minimum of one year of advanced training, flight evaluation and system upgrading of the LEM and its subsystems for the terminal descent phase of the manned lunar landing and return mission.

7.2 SUBSYSTEMS GROUND TESTING

Initial subsystem testing is to provide design data and information on which to base component selection. As the LTA-9 design progresses, ground tests are depended upon for ascertaining the correctness of design approaches, component sections and subsystems. Table 7.1 lists and classifies the major ground tests from the component level through subsystem. A brief description of these tests or test sequences follows:

7.2.1 Material and Components

Grumman's background in manned aircraft and the concurrent LEM development will result in minimum material and component testing. These tests should be limited to static tests of structural elements, operational and strength tests of mechanisms, brief environmental testing and duty cycling of equipment unique to the atmospheric free-flight LEM.

7.2.2 Mechanical/Electromechanical Drives and Linkage

These tests will assist in the development of mechanical drives and, subsequently in the mechanical operation, dynamic response and proper initiation of key LTA-9 drives and linkage. Such items include levitation system power actuators, and the electromechanical sections of the EECS.

7.2.3 Wind Tunnel

The aerodynamic characteristics of the LTA-9 configuration will be determined with scale models in the Grumman wind tunnel. These tests will be conducted at Reynolds numbers corresponding to full scale velocities over the actual LTA-9 flight envelope. In addition to providing basic aerodynamic data, proper wind tunnel testing will indicate buffet conditions and confirm design modifications to minimize separation, buffet and other objectional aerodynamic characteristics.

7.2.4 Ejection Seats

Crew escape subsystem development will initiate with structural testing of the ejection seats, and seat support structure. Assuming the use of RAPEC III type rocket ejection seats, the seat will undergo dynamic firing tests utilizing a representative LTA-9 cockpit enclosure. These tests will demonstrate the hatch ejection-seat sequence and confirm occupant touchdown location with respect to the vehicle. The detail test plan for these firings will be tailored to escape system verification of LTA-9 and optimized for the LEM astronauts, rather than service pilots in general. Emphasis will be given to qualifying the ejection subsystem for the critical points of the LTA-9 flight envelope operating over a WSMR terrain and climate condition.

7.2.5 Vehicle Safety

Should design studies result in a vehicle recovery approach, development and design feasibility testing will be used to assess devices for protecting LTA-9 against damage. These devices include: low-level parachute recovery and velocity reduction systems; impact attenuation mechanisms, such as shock absorbers, crushable or yielding structure and pneumatic bags; and combinations of these methods. The most desirable approach will be ascertained during subsystem tests of boiler plate LTA/LEM structure, and reliability established prior to flight test.

TABLE 7.1

GROUND TEST SUMMARY
COMPONENTS THROUGH SUBSYSTEM LEVEL

TESTS	CLASSIFICATION *
1) Material and components	Development Design Feasibility
2) Mechanical/electro-mechanical drives and linkage.	Development Design Feasibility Design Verification
3) Wind tunnel models	Development Design Verification
4) Ejection seat	Development Design Verification Reliability
5) Vehicle safety, including chutes, and energy absorbing devices.	Development Design Feasibility Design Verification Reliability
6) Thrust vectoring hardware	Development Design Feasibility Design Verification Reliability Subsystem Qualification
7) Levitation propulsion subsystem without, then with LEM descent engine, including trim reaction control subsystem.	Development Design Verification Reliability Subsystem Qualification
8) LTA-9 Flight control subsystem, including bench, simulator and airbearing table tests	Development Design Feasibility Design Verification Reliability Subsystem Qualification
9) Electrical power supply	Development Design Verification
10) Electrical integration - bread-board through hardware and checkout.	Development Design Feasibility Design Verification Reliability

(continued)

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TABLE 7.1 (Cont.)

GROUND TEST SUMMARY
COMPONENTS THROUGH SUBSYSTEM LEVEL

TEST	CLASSIFICATION*
11) Radar and inertial platform bench and dynamic tests.	Design Verification Reliability Subsystem Qualification
12) Environmental control	Development Design Verification Subsystem Qualification

* CLASSIFICATION DEFINITION

Development	-	to provide engineering data
Design Feasibility	-	to aid in component/subsystem selection
Design Verification	-	to ascertain correctness of the design
Reliability	-	extention of development tests to determine the reliability prior to actual mission.
Subsystem Qualification	-	subjection of items to environmental stress level exceeding maximum mission design requirements.

7.2.6 Thrust Vectoring

Levitation jet nozzle gimbal development will begin early in the test program. After the design approach, for rotating the nozzles and controlling the vanes moving within the nozzles, has been substantiated, hot engine tests of a prototype tailpipe assembly will be performed. Since thrust vectoring is a prime requirement of the levitation propulsion subsystem, its reliability and environmental qualification will be established by test results prior to the completion of levitation propulsion subsystem tests.

7.2.7 Levitation Propulsion

Grumman will confirm the levitation propulsion subsystem prior to first flight. This task starts with development testing to establish the configuration's performance, fuel system characteristics and engine control requirements. Testing will continue through the stage at which the jet engine levitation subsystem is qualified and shown to perform with reliability. Further ground testing will continue until the levitation propulsion subsystem has been demonstrated to operate satisfactorily in conjunction with the LEM descent engine.

The propulsion testing will ascertain:

* Subsystem performance, including thrust, fuel flow, starting characteristics.
* Environmental conditions, including temperatures, vibrations, and acoustic noise.
* Thrust vector control (TVC) effectiveness, including thrust matching and parallelism of thrust vectors.
* Automatic control section's ability to program fuel and thrust; and cope with emergency modes (i.e., shutdown or increase thrust on specific engines).
* System response to programmed commands.
* Performance of bleed-air reaction controls for the EECS.
* Fuel system operation.
* Induction system design.
* Susceptibility to foreign object ingestion.

When the LEM descent engine is introduced, the above listed items will be re-evaluated. Additional consideration will be given to:

* Thermal environmental problems.
* Jet ingestion of rocket exhaust
* Evaluation of the automatic control section's ability to program thrust as a function of rocket fuel consumed.
* Simulated training mission thrust profiles.

Successful completion of the levitation propulsion subsystem ground tests will pave the way for tied-down and tethered LTA-9 vehicle propulsion tests, and the flight test program.

7.2.8 Flight Control

This system is unique to the LTA-9 vehicles and will require a developmental program to qualify it for all operational modes and possible flight operating conditions:

1. Fully levitation supported
2. Full earth environment compensation
3. Earth environmental compensation subsystem degraded
4. Full earth environment compensation with simulated LEM malfunctions (non-catastrophic).

Since thrust balancing and thrust vectoring are primary functions of the flight control system, developmental progress in this area will be closely integrated with the levitation subsystem testing (section 7.2.7). Similarly, close liaison with the basic LEM flight control development shall be maintained.

The ability of subsystem control loops to command and stabilize will be confirmed by either three-axis or air-bearing table tests. Introduction of disturbance torque inputs is accomplished through calibrated induction torquing equipment.

7.2.9 Electrical Power Supply

Primary power supply is a dual 28-volt battery subsystem. In addition to the battery, the subsystem includes regulation and inverter equipment. A complete set of LTA-9 or LEM electronic equipment for the sole use of a power supply subsystem test would be unwarranted (and difficult to provide early in the development program). Therefore, a load bank will be used to simulate the dynamic changes during the LTA-9 mission. These tests will cover power supply interfaces with other vehicle subsystems in operational and emergency conditions. The power supply tests will include the areas shown in table 7.2.

7.2.9 (continued)

TABLE 7.2

SCOPE OF LTA-9 POWER SUPPLY SUBSYSTEM TESTS

* Overall Subsystem Efficiency
* Transients
* Short-Circuit Effects and Fault Analysis
* R.F. Noise Generated by Power Lines and Cross Effects Between Lines
* Operating Temperatures of Power Supply Components
* Voltage Regulation
* Ripple on d.c. Lines and Harmonic in a.c.
* Load Switching Effects
* Operation under Simulated LTA-9 Loads and Duty Cycling
* Degraded Operation of LTA-9 Components and Resulting Effects on Power Supply Subsystem
* Environmental Qualification for Flight Mission at WSMR

7.2.10 Electrical Integration

Integration testing of electronic equipment is significant from the standpoint of LTA-9 reliability. The integration tasks to be accomplished here include:

* Breadboard tests of all electrical sections
* Bench checkout of all equipment before assembly into subsystems
* Interface compatibility verification of assembled subsystems before installation into LTA-9 vehicles
* Electro-magnetic interference tests
* Installation of electrical sections and intercabling into LTA-9 vehicles
* Modifications to electrical sections as required

7.2.10 (continued)

The bench checkout will include incoming acceptance testing of all equipment. These acceptance tests are minimal functional checkouts intended to uncover malfunctions caused by mishandling in transit. Preliminary integration tests in which interface problems can be resolved under the least complicated working conditions, will be performed at the assembly or subsection level.

7.2.11 Radar and Inertial Measuring Unit

Absolute altitude, altitude rate, and horizontal velocity information will be derived from the LEM radar section. Three-axis attitude, rate, and acceleration will be provided for control signals, pilot's displays and error information to the automatic levitation engine control subsystem and EECS.

Radar Testing: The use of a radar-type device to control rate of descent is dependent upon the generation of radar displacement and rate signals reasonably noise-free. The problem of looking through the exhaust of the descent rocket with radar signals and achieving a desirable signal-to-noise ratio will be investigated. It is anticipated that from the development through the LTA-9 flight test period, close and mutual exchange of information and results will be maintained between the LEM and LTA-9 in the radar area.

Prior to the LTA-9 flight testing, laboratory and dynamic ground tests will be conducted. The laboratory tests will concentrate upon the analysis of recorded radar return signal in the control frequency spectrum to separate rate-of-descent and exhaust generated distortion frequencies. Adjustment of RF components and checkout of instrumentation will be made under dynamic test conditions. Helicopter-mounted tests could provide a platform for adjustment of radar data processing units and antenna boresighting. These dynamic tests will be conducted within the limits of radar beam distortions caused by unrealistic ground planes.

Flight tests in the LTA-9 will be used for final adjustment and calibration of radar equipment under conditions where the jet engine exhausts as well as the LEM rocket engines exhausts are prevalent.

Inertial Measuring Unit: Before conducting tests aboard LTA-9, the inertial reference equipment will have been environmentally qualified and its reliability demonstrated in the laboratory (Section 7.2.8) and in flight tests. Since the gyro reference will be an important part of the levitation engine thrust vector controller, it is desirable to man-rate the section under conditions where its output is not essential to flight safety. Mounting the equipment in a helicopter in conjunction with the LTA-9 electrical power supply and recording x, y, and z outputs under conditions of large translation and at rates compatible with the LTA-9 requirements will afford this opportunity. These runs would be repeated and the data examined for accuracy, reliability, drift rate, encoder or adapter wear, or any other degradation. In order to substantiate the flight data, optical tracking or vertical photography from the ground will be used.

7.2.12 Environmental Control

These tests, in general, entail the measurement of temperatures, pressures, and flow rates in both the life support section and equipment environmental control section (the latter implies measurements of the onboard equipment being cooled also). Development testing will be performed on flow benches. The adequacy of coolant flow through equipment and heat exchangers will be determined under LTA-9's design operating range. Onboard subsystems for which cooling must be verified include LEM, LEM modified and unique LTA-9 equipment. The life support section must guarantee the safety of the crew against the toxic products of combustion of the LEM descent engine, reaction control jets, as well as the jet engine exhausts. Design verification and environmental control subsystem qualification will be performed using the LEM internal environment simulator facilities. Further refinements in flow balance and optimization of regulator controls will be performed during ground tethered and free-flight testing aboard the LTA-9.

Comprehensive and effective subsystem ground testing can be achieved economically through the use of in-house LEM test facilities and integration of applicable basic LEM development test results and experience. As noted before, distinct time savings arise in virtually all subsystem development areas. The subsystem testing program illustrates that close liaison with the LEM subsystem engineering groups will provide on-time delivery of a functional terminal descent training vehicle.

7.3 VEHICLE TESTING

LTA-9 will be qualified for its flight training mission by a carefully designed ground and flight test program. This test plan will result in delivery by Grumman of two flight-proven LTA-9 vehicles to the NASA by the end of 1966. This schedule will permit the astronauts one year of advanced free-flight training operations in craft with proven reliability.

Basically, the integration of the LTA-9 structural integrity ground testing program with that of the LEM, in particular LTA-2 and LTA-3, results in the need for "proof testing" LTA-9 rather than an "ultimate strength" demonstration. From a manufacturing point of view, the fabrication, assembly, and fixture utilization of an additional flight article is comparable with a static test LTA-9.

In weighing the advantages of commencing the flight test program at the earliest possible date against the desires to maximize the results of LTA-9 and LEM preflight ground development tests, and to resolve system problems under more controlled and less complicated laboratory conditions, the virtues of two flight articles are apparent. Having two vehicles available for flight testing in mid-1965, along with a strong background of subsystem testing and proven structural integrity, increases the probability of program success. This plan permits two years (from mid-1963) in which to design, fabricate, assemble, and conduct most of the subsystem tests discussed earlier.

Since the jet engine-only flight mode is primary for takeoff and emergency conditions, initial flight testing is with the levitation engines only. It is recommended that this early flight qualification testing be conducted at Grumman's Peconic River facility so that LTA-9 and LEM engineering talent is readily available. Following the progression of tied-down, tethered, and free-flight testing with the levitation engines, No. 2 LTA-9 will join No. 1 vehicle at White Sands Missile Range in mid-1966 where both vehicles will participate in the final flight qualification tests, involving the levitation and LEM propulsion systems.

Delivery of the LTA-9 vehicles to NASA occur shortly after the first manned C-1B-LEM space flight test. (See figure 7.1). From that point on, the primary task of the Grumman test organization will be to assist the NASA in incorporating up-to-date LEM flight information into the LTA-9 flight program. In this manner, LTA-9's role in advanced training and functional testing of LEM equipment will be continually updated.

7.3.1 No. 1 LTA-9 - Ground Testing

LTA-9 structure will be qualified using the No. 1 flight vehicle. Proof loads simulating critical conditions will be applied to the structure and monitored using strain gage circuitry. Recorded stress-strain data will be compared with predicted stresses to substantiate analysis and design assumptions. LTA-9 structural sections which remain unchanged from the basic LEM will be qualified during the LTA-3 structural test program. Vehicle drop tests to establish landing gear response characteristics and verify gear analysis and design will be

7.3.1 (continued)

performed for both the "workhorse" gear and the simulated LEM gear. A full-scale ground vibration survey to ascertain model frequencies and shapes will also be conducted on the No. 1 vehicle before it is flight tested. The proposed ground testing schedule and its relation with the pertinent LTA and TM tests of the basic LEM program are shown in figure 7.1.

A short discussion of the major structural tests to be conducted with the No. 1 LTA-9 follows:

7.3.1.1 Control System

These tests will be performed on the mechanical portion of the control system used to control the levitation engines and trim the vehicle. The control system, installed in the LTA-9 vehicle, will be subjected to proof loads for each of its critical design conditions. Test loads will be applied by blocking off the system under test and applying loads through control actuators.

7.3.1.2 Seat Support Structure

The seat support structure will be subjected to proof loads duplicating the critical loading conditions as determined by analysis. The test loads will be distributed to the structure through a fixture attached to the seat support hardware. Balancing loads will be applied to the LTA-9 structure in such a manner as to balance the test loads without exceeding local design criteria.

7.3.1.3 Engine Mounts

These tests will be performed to demonstrate the strength of the levitation engine system support structure. Proof test loads, applied to a fixture simulating the engines will duplicate the critical design loading. Balancing loads will be applied to the LTA-9 structure as above. Reaction control supports will undergo a similar testing procedure.

7.3.1.4 Landing Gear and Landing Gear Support Structure

During these tests the LTA-9 main and auxiliary gears will be subjected to static loads simulating critical landing conditions. The proof test loads will be applied directly to the gear assembly which will be installed on the LTA-9 vehicle. Vehicle balancing loads will be applied as before.

7.3.1.5 Vehicle Drop

The initial portion of the Phase I ("workhorse" gear) drop test program will be performed to evaluate gear energy absorption characteristics. Once these are established the program will be expanded to include drops up to combined touchdown velocity components of 5 fps horizontal and 10 fps vertical.

7.3.1.5 (continued)

The following vehicle landing attitudes will be investigated:

* 2 point taildown - translational drops
* 2 point nose down - translational drops
* 4 point - combined translational and horizontal drop
* 2 point tail down - combined translational and horizontal drop
* 2 point nose down - combined translational and horizontal drop
* 1 point tail down - roll 10^{o} translational
* 1 point tail down - combined roll 10^{o} translational and horizontal.

The Phase II drop test program using the alighting gear design to simulate the LEM's landing dynamics will be similar to the Phase I gear. The LTA-2 LEM stability drop test program will be reviewed and where applicable, results, techniques and equipment will be incorporated.

7.3.1.6 Vibration

A ground vibration survey will be conducted to determine modes and frequencies. Low frequency modes will be used to determine possible interactions between structural modes and the stabilization and control subsystem. In addition, higher frequency modes and transmissibility information will be obtained to assist in evaluating the unsteady thrust from the rocket and jet engines during firings; and the elastic response to firing transients and landing loads.

Analytic and experimental investigations of the oscillatory pressures due to exhaust impingement and sonic excitation will be conducted. The LTA-9 structure will be designed to withstand sonic fatigue due to these sources and to furnish an internal acoustical and vibration environment adequate for proper operation.

7.3.2 Flight Testing

Flight testing may be categorized into three broad areas:

Category I - Jet levitation supported flight tests (EECS both "off" and "on").

Category II - Combined levitation, EECS and LEM descent engine flight tests with a conventional landing gear.

Category III - Combined levitation, EECS and LEM descent engine flight tests with a LEM type landing gear.

The flight testing to qualify the LTA-9 vehicles for astronaut usage includes propulsion/performance tests, flight control and systems testing; structural and dynamics testing and demonstration of landing gear suitability.

The jet powered tests (Category I) initiate with tied down and tethered flight tests and build up to free flight tests. These tests will be performed with the No. 2 LTA-9 at Grumman's Peconic Flight Test Facility beginning in mid-1965. All testing (Categories II and III) involving LEM rocket or RCS firing will be performed at White Sands Missile Range. These latter tests include fully tethered, partially tethered and free flight operations. Number 1 LTA-9 vehicle with LEM rocket engine equipment is used in the Category III tests in mid-1966, after completing the ground proof test program. Number 2 vehicle joins Number 1 at WSMR shortly thereafter. The WSMR facility and equipment requirements to support LTA-9 test and flight operations are discussed in section 8.2.

A brief discussion of each major test area in the flight test program for the atmospheric, terminal descent training vehicles follows:

7.3.2.1 Propulsion/Performance - The primary purpose of the integrated LTA propulsion tests is to prove system adequacy and reliability. Final adjustments will be made initially with the jet levitation propulsion and control subsystem and subsequently with both the jet and LEM rocket propulsion sections operative.

7.3.2.1.1. Tied Down Tests - During the tied down LTA-9 test the environmental effects of temperature, structural vibrations and oscillatory pressure disturbances generated by the propulsion subsystem will be evaluated. During the initial or jet levitation powered tests three axis force measurements will be made. The vehicle will be secured in the test cell. This test cell will be designed to minimize recirculation, debris and exhaust injection problems during test runs. After checkout, operational and performance characteristics will be evaluated in thrust magnitude and thrust vector control runs. For fully restrained firings at WSMR a force measurement test cell will not be required.

7.3.2.1.2. Tethered Tests - Tethering will permit the safe determination of LTA-9 propulsion system characteristics, including altitude and attitude hold under dynamic conditions. Engine checkout will be under manual and automatic flight control subsystem inputs. Close coordination will be maintained with the flight control systems test group during these tests.

Specific test objectives during these tests include:
* Thrust vector effectiveness
* Response to automatic control and manual control inputs
* Demonstration of engine-out capability
* Determination of wake profiles in area of ground exhaust plane
* LEM rocket engine starts (Category II tests)
* Rocket - Jet interaction (Category II tests)

The tether or hover facilities contemplated for these tests are simple rigs, possibly of the gantry, winch-cable variety. During the levitation jet engine tests the runway could be protected with steel mesh mats or boiler plate. For the tethered testing at WSMR, a takeoff platform with a manhole in the middle to collect and direct exhaust products would be added.

The tethering equipment would be dispensed with as soon as possible. However, it could be utilized again in the Astronaut Flight Program to provide a new pilot with confidence in his ability to control height, attitude and "feel out" LTA-9 touchdown dynamics. The takeoff platform at WSMR would be utilized throughout the free flight test phase and Astronaut Flight Program.

7.3.2.1.3 Free Flight Tests - Evaluation and confirmation of LTA-9 performance using levitation and subsequently levitation and LEM rocket power will be performed in free flight. Included in the performance/propulsion and reaction control investigation are fuel requirements, turbojet induction system characteristics, climb performance, translation, including drag and velocity profiles, and descent performance in the manual and automatic flight modes.

7.3.2.2 Systems - Systems testing on assembled LTA-9 vehicles includes verifying, quantitatively, the performance of each subsystem over its functional dynamic range with each subsystem operative in its intended flight environment. These tests will be particularly useful in "debugging" the integrated sybsystems. System calibration tests will also be performed after the functional performance tests. The major effort will encompass the earth environment flight control and stabilization subsystem, the life support and equipment environmental subsystem, the communication and power supply subsystems.

7.3.2.2.1 Earth Environment Compensation (EEC) - During the LTA-9 tied-down and tethered flight tests operation of the jet thrust and thrust vector control section would be refined, gain settings optimized, thrust balancing control confirmed. The inertial reference will also be upgraded during these tests since ground loops, magnetic fields and biasing are functions of the installation and vehicle structure. These tests aboard an actual LTA-9 will provide the opportunity to upgrade the LTA-9/LEM IMU under least troublesome conditions. Platform drift rate runs will be made with and without other LTA-9 equipment operating to confirm bias settings, need for magnetic shielding, and power supply transients.

During the tethered tests the effects of airframe and acoustic vibrations on subsystem outputs will be measured and the adequacy of mounts and microphonics checked. Mounting modifications and filtering will be incorporated as required.

After achieving sufficient confidence in system reliability from the tie down - tethered system and propulsion tests (sections 7.3.2.1.1 and 7.3.2.1.2) free flight testing will commence. The EECS free flight testing will be closely associated with stability, control and flying quality testing. Free flight tests would yield final proof of the coupled thrust vector control, inertial and gyro components of the EECS and would effectively constitute system demonstration. Final adjustment of radar altimeter's data process units, antenna loop angles and other variables required achieve a successful transformation from video to a signal of high accuracy will be implemented. These free flight tests will provide the three axis information necessary to calibrate the radar equipment under conditions of rocket and jet engine exhaust.

7.3.2.2.2 Additional Subsystems Tests - The life support and equipment environmental control subsystem would be operated in ground and tethered flight tests to "debug" the subsystem under actual LTA-9/earth flight environment conditions and to refine coolant flow balance. These tests would consist of monitoring pressures, temperatures and flow rates during free flight tests.

LEM VHF communication and intercom equipment could be utilized aboard LTA-9; however, standard aircraft type communication would also suffice. In any event, communication subsystem tests should not be extensive. These tests include antenna pattern checks, and verification of adequate vehicle-to-ground, vehicle-to-air communication and onboard (intercom) under all operating conditions.

7.3.2.3 Flying Qualities - LTA-9 stability and control criteria will be confirmed by flight testing. Prior to and during the tethered and free flight flying quality investigation, the test team will maintain close liaison with the LTA-9 wind tunnel and LEM simulator groups. This background is to be established for a two-fold purpose:

1) To apply the test results and simulator experience for test planning and test instrumentation requirements.

2) To assure that the data acquired in flight test will afford ready comparison with earlier LTA-9 and LEM analytical and ground test information.

Similarly, within the flight test organization, working knowledge of the flight control systems and propulsion test engineers progress will be maintained by the Stability and Control group. It is anticipated that the major S & C effort will be expended in the initial test phase of No. 1 vehicle in the Levitation Power (Category I) configuration. Subsequently, the flying qualities of LTA-9 with the addition of LEM Propulsion will be substantiated at WSMR.

A summary of the major task areas to be considered in the LTA-9 handling qualities tests is present in table 7.3

TABLE 7.3

Major LTA-9 Flying Qualities Flight Test Areas

*Take-off - Control effectiveness and response initially in tethered flight, then free flight. The objective will be to demonstrate adequacy and margins in take-offs throughout the range of LTA-9 operational weights.

* Transition -
Technique required for air start of rocket engine.

* Longitudinal Static Stability and Control-
Investigation of the LTA-9 in hover and throughout its speed envelope for various c.g., conditions. Controllability while maneuvering close to the ground and the effects of downwash, recirculation and interference will be confirmed.

*Trim - Trim changes due to aerodynamics, power, fuel variation and misalignments will be assessed.

* Dynamic Stability -
Because of LTA-9's pronounced dependence on automatic stability features, dynamic stability checks will be performed in all modes of flight operation and the characteristics of LEM and EECS stabilization and control elements verified, particularly with regard to gyroscopic, and inertial coupling. This vehicle response data will help determine the minimum levels of LTA-9 stability in its subsequent utilization by the astronauts.

* Lateral and Directional Stability and Control -
In addition to assessing the pitch plane handling characteristics, the lateral and directional qualities of LTA-9 will be checked throughout the vehicle's flight envelope.

* Landing -
Safe and controllable procedures for normal and emergency landings, including engine-out conditions, will be defined within the limits of LTA-9 structural integrity.

7.3.2.4. Landing Gear - The ability of both the conventional wheeled gear for use in categories I and II, and the LEM simulated stability gear of category III to perform the tasks for which they were designed will be demonstrated in flight test. In all gear testing, buildup maneuvers will be utilized to establish load trends which in turn will enable extrapolation of test data to potentially critical conditions. The use of a buildup approach (tethered flight preceding free flight) will aid in pilot familiarization with the LTA-9/gear dynamics. During the tethered and free flights, a qualitative analysis of cockpit visibility and landing aids will be made.

The landing gear flight test program is highlighted in the following paragraphs:

7.3.2.4.1 Lift-off - Take-offs will be performed, initially with tethering then free flight in both the wheeled ("workhorse") and simulated LEM landing gear configurations. These tests will demonstrate that the LTA-9 can be lifted off from such terrain required to simulate its terminal descent landing mission. It will be demonstrated that lift-off is not dependent upon unusual control manipulations and that adequate control effectiveness exists to prevent undesirable pitch or yawing attitudes that might endanger the vehicle or gear.

7.3.2.4.2 Landing - The LTA-9 landing tests will be conducted to design limit load and load factors and to the most critical allowable loading attitude for the LTA-9 LEM configuration. These tests will confirm the earlier ground drop tests performed with No. 1 LTA-9 (section 7.3.1.5). The anticipated test landing conditions are summarized in table 7.4.

The adequacy of the control to maneuver LTA-9 safely with no undue manipulations will be demonstrated. In addition, the ability of the vehicle to recover from unusual touchdown attitudes will be confirmed during the tethered flight phases. To simulate the righting moment of the LEM a reduced diameter (to compensate for lunar gravitation) five point alighting gear with landing pads may be utilized. These tests will be performed with the LTA-9 ballasted, if necessary, to duplicate LEM center of gravity and inertias. Righting moment will be demonstrated initially in tethered flight with forward velocity component induced by inclination of the vehicle or landing surface if it is not practicable to attain the desired actual forward velocity.

Table 7.4

PRELIMINARY LANDING GEAR FLIGHT TEST OUTLINE

A. LANDING CONDITIONS

1)	Symmetrical	5-point (category III gear)
2)	Nose Down	- 10° maximum
3)	Rolled	± 10° maximum
4)	Tail Down (single base)	+ 10° maximum

B. PROPOSED SEQUENCE

The four conditions noted above will be investigated initially, tethered than free-flight, in the following order:

Configuration

I. Levitation System Installed - & Operating
   a) Wheeled ("Workhorse") Gear
   b) LEM Simulated

II. Levitation System plus LEM Descent Engine
   a) Wheeled Gear
   b) LEM Simulated

III. Most Critical Attitude to Demonstrate Righting Moment
   a) Wheeled Gear
   b) LEM Simulated

C. CURRENT DESIGN LIMITS

Free-flight sink speed	10 fps
Horizontal speed component	5 fps
Maximum height drop from 4 fps tether condition	10'
Vehicle attitude	5° inclination of vertical (X) axis

7.3.2.5 Structural and Structural Dynamics - Structural flight testing will be performed to substantiate the structural integrity of the vehicle under operational flight conditions throughout the LTA-9 flight envelope. Load, temperature and acceleration measurements will confirm the ground static and vibration tests discussed in Section 7.3.1 or bring to light any deficiencies that could not be detected from analysis at lower levels of testing. Table 7.5 outlines the flight environmental problems to be investigated during the flight testing period.

Table 7.5

Structural Flight Test Evaluation Areas
Tether and Lift-off
Tether tie-down loads (tethered to a rig or helicopter)
Engines start transients
1. Engine characteristics.
2. Structural response from engine starts.
Engine Induced Loadings
1. Local buckling due to pressure pulses.
2. Coupling of acoustic energy with structure: structural resonances, motion response, component response, fatigue damage.
3. Damping of vibrations, linear and nonlinear response.
4. Engine-attributable thermal loadings.
Subsystem Interactions
1. Response during simultaneous effects of engine motions and thrusting, control thrust and gusts.
Atmospheric Free Flight
Interaction of structure and onboard subsystems
1. Aerodynamic forcing - buffeting, noise, flutter and aeroelastic phenomena.
2. Engine thrust variation and random excitation, nozzle impingement.
3. Fuel sloshing.
4. Mass rate of change effecting changes in c.g., moments of inertia and damping.

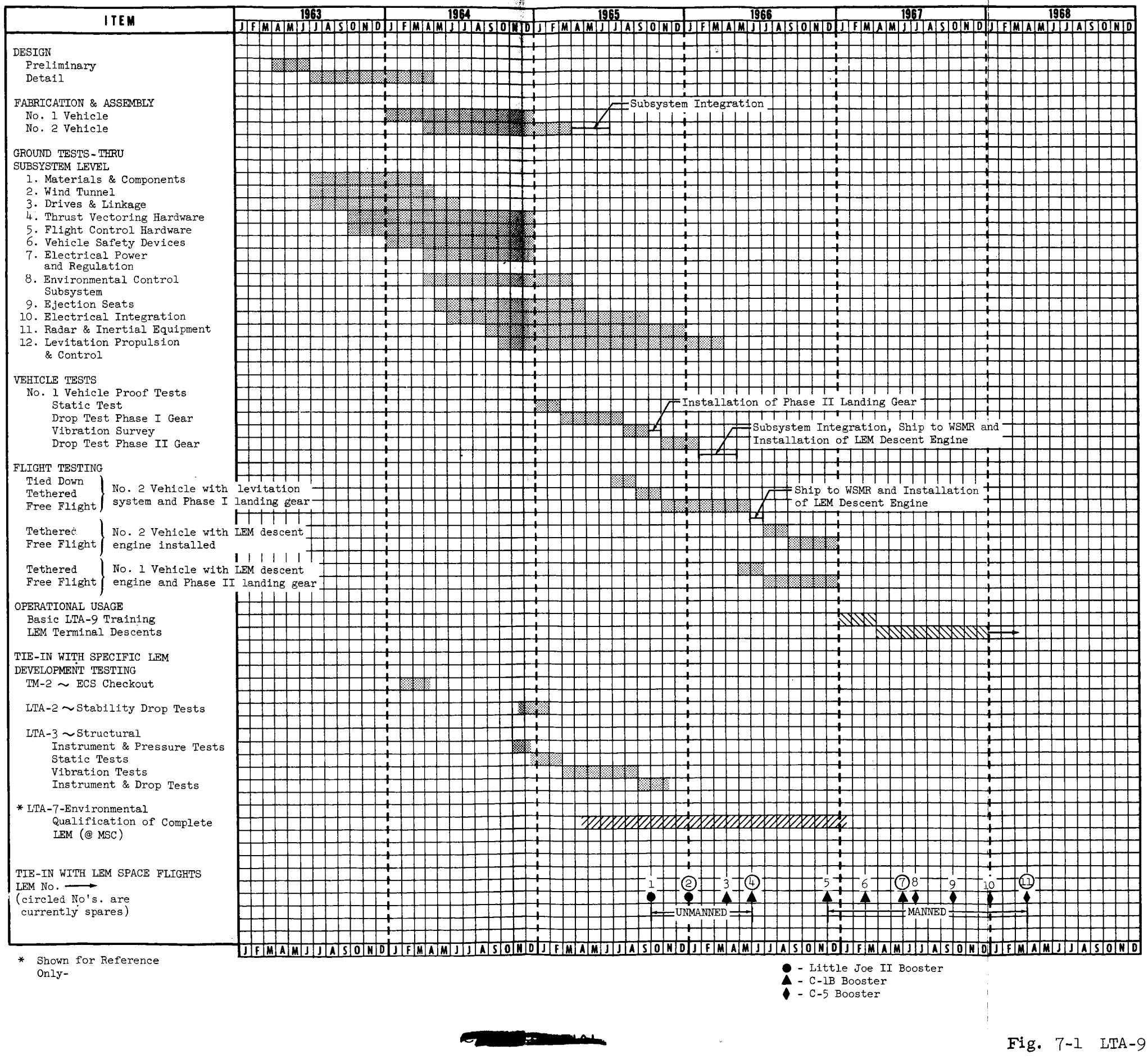
7.4 ALL ROCKET CONFIGURATION - The development of an LTA-9 powered, solely, by a modified LEM descent engine and controlled using modified LEM RCS could result in an early operational usage date. The design aspects and performance of the all-rocket configuration are discussed in sections 5 & 6. Earlier operational usage (May 1966 as compared to January 1967) is achieved because of the all-rocket vehicle's closer similarity to the basic LEM than the jet levitation conceptual configurations.

Calendar time and testing time savings result throughout the component level through subsystem level testing period. However, ejection seat tests, vehicle recovery and safety device testing, ECS and to a large extent the wind tunnel tests will be identical in scope to those tests required for the jet levitation configuration. The availability of major hardware items, e.g., the modified LEM descent engine also provides a restraint on earlier LTA-9 delivery.

Complete vehicle ground testing time can be reduced somewhat, however, LTA-9's structure is to be designed for repetitive flight and landing operations and complete reliance upon the basic LEM structural, vibration and drop testing is not in order.

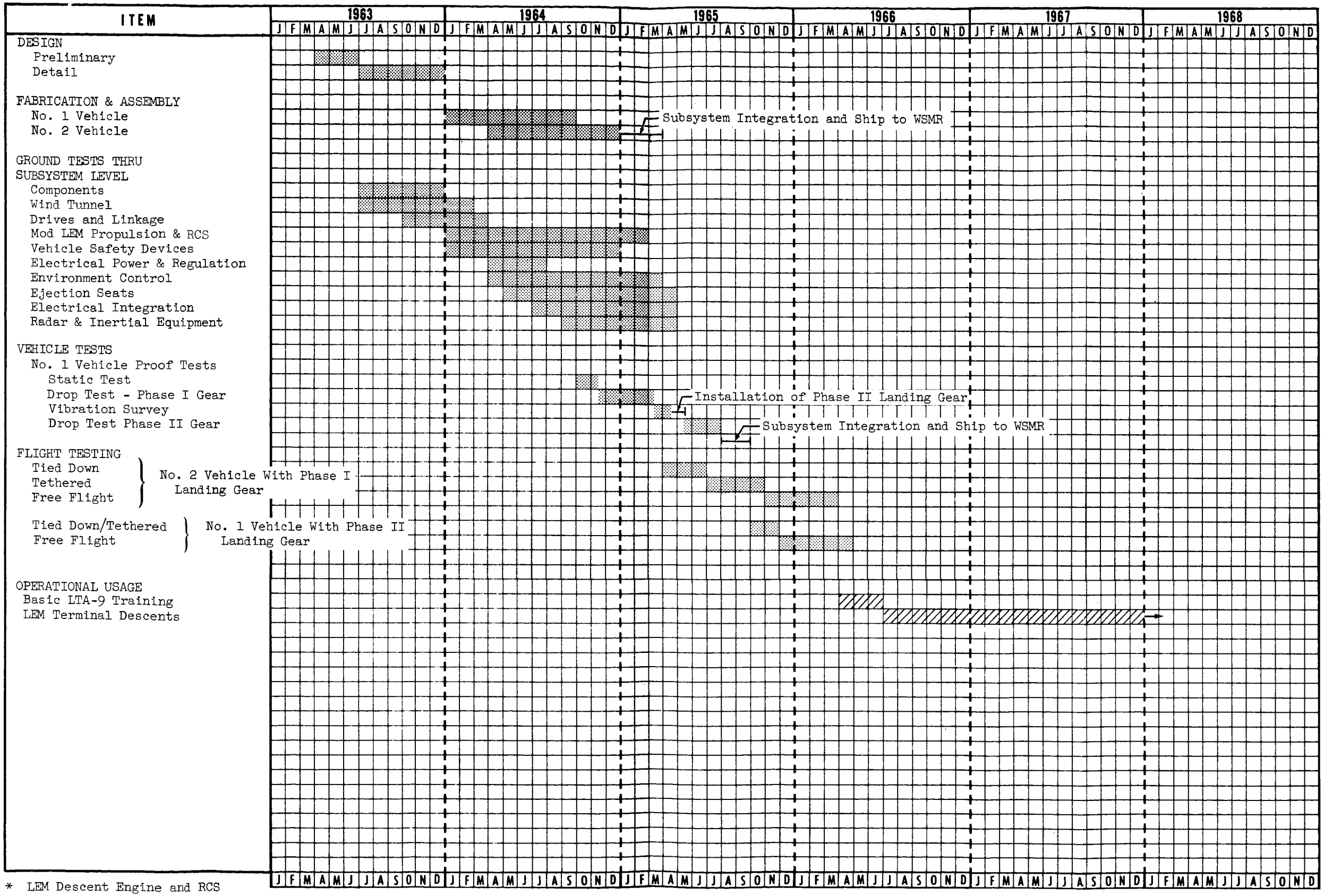
The entire flight test program for the all-rocket configuration is best suited for White Sands Missile Range. The importance of a comprehensive flight test program for this configuration is underlined by the fact that in an emergency, the all-rocket configuration cannot rely on the backup turbojet thrust and bleed air reaction control afforded by the "levitation LTA-9" concept. One of the consequences of conducting the complete LTA-9 flight test phase at WSMR would be additional instrumentation requirements for LTA-9 tied down and tethered test facilities.

A preliminary development program schedule for the all-rocket LTA-9 configuration is presented in figure 7.2.



* Shown for Reference Only-

Fig. 7-1 LTA-9 Development Program Schedule



* LEM Descent Engine and RCS Modified for Atmospheric Flight

Fig. 7-2 All-Rocket* LTA-9 Development Program Schedule

8. OPERATIONAL UTILIZATION

8.1 PRELIMINARY TRAINING MISSION DESCRIPTION

8.1.1 LTA-9 Basic Flight Training

Flight operations by the astronauts will parallel the tied down - tethered - free flight sequence of the flight test phase described in section 7.3.2. Considering 1) the physical similarity between the LEM and LTA-9 crew compartments (see tables in section 4.1); 2) the astronaut's prior experience in fixed and moving base LEM simulators and, 3) LTA-9 was flight tested and qualified prior to astronaut usage, the Basic Flight Training Period should be, nominally, three months. The availability of LTA-9 for LEM terminal descent experience prior to the first manned lunar landing will be, therefore, at least nine months.

As in the flight testing phase, the initial flight training will be in the jets-only or levitation mode of flight power and control. Following the levitation mode training, operations with the jets and LEM descent engine will commence. It is recommended that, initially, the astronaut training concentrate on LTA-9/LEM flight dynamics and handling characteristics. The conventional wheeled landing gear is readily interchangeable with the LEM simulated alighting gear. As an astronaut crew gains flight handling proficiency with the wheeled gear configuration they can advance to the LEM simulated vehicle and proceed with combined flight dynamics and landing dynamics training. Depending upon the number of crews and detailed LTA-9 astronaut usage plan, one of the two LTA-9 vehicles may be equipped with a wheeled landing gear throughout 1967.

8.1.2 LTA-9 Mission Profile

The terminal descent mission profile for LTA-9 encompasses a continuous trajectory from, what is termed in the LEM Proposal, the hover point to the completion of the landing dynamics, see figure 8.1. While the entry condition is not limited to a hover, the maximum velocity of LTA-9, nominally, 75 fps restricts the LTA-9 from the high velocity deorbit and flare portions of the lunar descent. The terminal descent experience will be "proof exercise" aboard a LEM type vehicle.

This exposure would follow the astronaut's training in fixed based simulators, moving base simulators and trainers including the tethered Langley Lunar Landing Research Facility and interim flight trainers such as: helicopters, X-14A VTOL, Bell Lunar Landing Research Vehicle. As illustrated in the development program schedule, figure 7.1, the training period would coincide with the manned C-1B and C-5 boosted space flights of LEM 5 through 10. The terminal descent experience would be provided during a period where the astronauts have been trained to a relatively high degree and at a time when space flight test results may be integrated into the LTA-9 vehicles.

8.1.3 LTA-9/LEM "Proof Exercise" Period

During the nominal nine month LTA-9/LEM terminal descent "proof exercising" it is anticipated that an average of four flights per week will be flown on the two vehicles utilizing LEM rocket propulsion. Using a nominal 120 second LEM descent operation per flight, four flights per thrust chamber will result. It is estimated that forty thrust chambers and six LEM descent engine assemblies would be utilized over this training period.

The detailed flight handling and rocket engine management profiles and advanced training task for each of the two LTA-9 vehicles is premature for the scope of this feasibility study. However, the "proof" of training and LEM upgrading flight schedules would include solely jet supported LTA-9 missions as well as combined LEM descent rocket and levitation propulsion.

8.2 FIELD SUPPORT REQUIREMENTS

Additional equipment, beyond that provided for the basic LEM Program, will be required to support the LTA-9 test vehicles because of the scheduling and scope of the LTA vehicles and, schedule changes. A schematic flow diagram for the two LTA-9 vehicles from Grumman's facilities to operational usage at WSMR appears in figure 8.2.

Support and maintenance equipment will be required to handle the SJ-132 engines. The majority of the equipment will be purchased from the engine contractor (G.E.) and adapted for operations by Grumman.

Certain LEM handling and transportation equipment will be duplicated to adequately support the test vehicles now scheduled for concurrent use at the test site (WSMR).

Additional equipment will be required to support items peculiar to the LTA-9 concept, such as, battery power, landing gears, and ejection seats in addition to the abovementioned jet engines.

Finally, some additional GFE items will be required for handling and recovery of the vehicles.

1. Specific additions due to scope of the LTA-9 mission:

   * Handling dolly - SJ-132 engine pod
   * Hoisting sling - SJ-132 engine positioning
   * Hold down fixture - static firing
   * Support cradle - recovery rig
   * Handling dolly - LTA-9
   * Protective covers - direct plugs etc.
   * Draw bars - LTA-9 towing
   * Engine installation fixture - modified LEM
   * Special tools
   * Work stand
   * Boarding ladders
   * Tethered flight rig
   * Ground mats
   * Assembly fixture - join stages and install gear

2. Additions due to schedule change - recurring charges

   * LEM shipping container (air conditioning not required)
   * Handling dolly - ascent stage, descent stage
   * LEM hoisting sling

3. Additional GFE

* Recovery vehicle - flat bed tractor trailer
* Mobile crane - 8 ton crane
* Air started - GTC-85 as required for SJ-132
* Power supply - 90 KVA
* Fuel supply truck - SJ-132 fuel
* Helicopter (Chinook HC-1B or equiv.)

The utilization of key equipment and facilities supporting the LTA-9 movements from design through operational usage is summarized pictorially in figure 8.2.

8.3 CREW SAFETY PROVISIONS

The physical hazard associated with free-flight of a vehicle that cannot rely on conventional wing or rotor lift is obvious. Levitation system reliability in regard to LTA-9 attitude control as well as braking thrust is essential. Nevertheless, a crew escape system is considered priority equipment for LTA-9. Crew safety studies have resulted in feasible ejection seat provisions for each crewman.

A lightweight rocket-powered ejection seat utilizing developed* RAPEC III components can meet the low speed and altitude initiation requirements of LTA-9 for ejection at various rates of descent. Figure 8.3 compares the results of a recent low horizontal velocity, zero altitude RAPEC III test at Grumman with an estimated trajectory of the modified RAPEC III. For a specific LTA-9 installation, the maximum roll, pitch and yaw attitude limits, and tolerable misalignment for safe recoveries must be substantiated by actual test demonstrations (see section 7.2.4). Similarly, the maximum vertical sink rate for a successful ejection, in combination with respective altitude data, also must be confirmed by tests. An indication of the proposed ejection seat's ability to effect a safe recovery under various LTA-9 rates of descent and orientations is shown in figure 8.4.

Table 8.1 itemizes a lightweight seat escape system which utilizes existing and tested components. In addition to providing a nominal 30" X 30" ejection clearance envelope and hard points for mounting such an escape system, consideration must be given to support, restraint, and mobility of a man in an Apollo-type pressure suit. While the RAPEC III Navy-type installation is illustrated herein, additional study is being given to a Gemini-type ejection seat (Weber Aircraft Corp., Burbank, California).

* Developed by Naval Ordnance Test Station, Inyokern, California.

TABLE 8.1

LIGHTWEIGHT SEAT ESCAPE SYSTEM USING EXISTING AND TESTED COMPONENTS

	ITEM	Source	Weight - LB.
1)	Time Release Mechanism, 2 Seconds	GRU-5	4.87
2)	Drogue Gun, 0.5 Seconds	GRU-5	3.15
3)	Weighted Drogue Piston	--	0.50
4)	Drogue Cartridge	GRU-5	0.10
5)	Main Beams	A-5	29.75
6)	Seat Bucket	A-5	25.64
7)	Head Box (including drogue system)	A-5	11.50
8)	Back Support Plate	GRU-5 RAPEC	2.56
9)	Inertia Reel	P.8	2.03
10)	Personnel Parachute Assembly	24-ft. dia.	20.60
11)	Rocket Catapult	RAPEC III	34.00
12)	Seat Cushion	J-5	2.50
13)	Back Cushion	GRU-5	1.52
14)	Lower Restraint Harness	J-5 type	3.27
15)	Oxygen and Communications Disconnect	GRU-5	2.32
		Total Weight	144.31 lbs.

NOTES: 1) No seat survival equipment is included.

2) Approximately 10 lbs. could be removed with minor component re-design (i.e.: removal of seat bucket, secondary firing control, actuators, etc.)

8.4 VEHICLE RECOVERY PROVISIONS

The feasibility of (a) a forcibly ejected pilot chute system, (b) forcibly ejected recovery chutes and, (c) the rapid deployment Stencel parachute system (see Reference-1* for description) have been reviewed in an effort to arrive at a vehicle-sized parachute recovery system. The more conventional parachute recovery methods, (a) and (b), result in estimated minimum safe recovery altitudes of between 800 and 500 feet, respectively, at the relatively low airspeeds inherent to LTA-9 flight operations. An estimated minimum recovery height for the Stencel system, (c), under zero airspeed conditions is between 100 and 150 feet.

Figure 8.5 indicates touchdown descent velocity as a function of recovery parachute system weight for a Stencel-type installation. A typical system for a 5000-lb vehicle landing at 30 ft/sec is:

2-50-ft Parachutes	103 lbs
Deployment bag and risers	20 lbs
Catapult and spreader slugs	57 lbs
Total	180 lbs

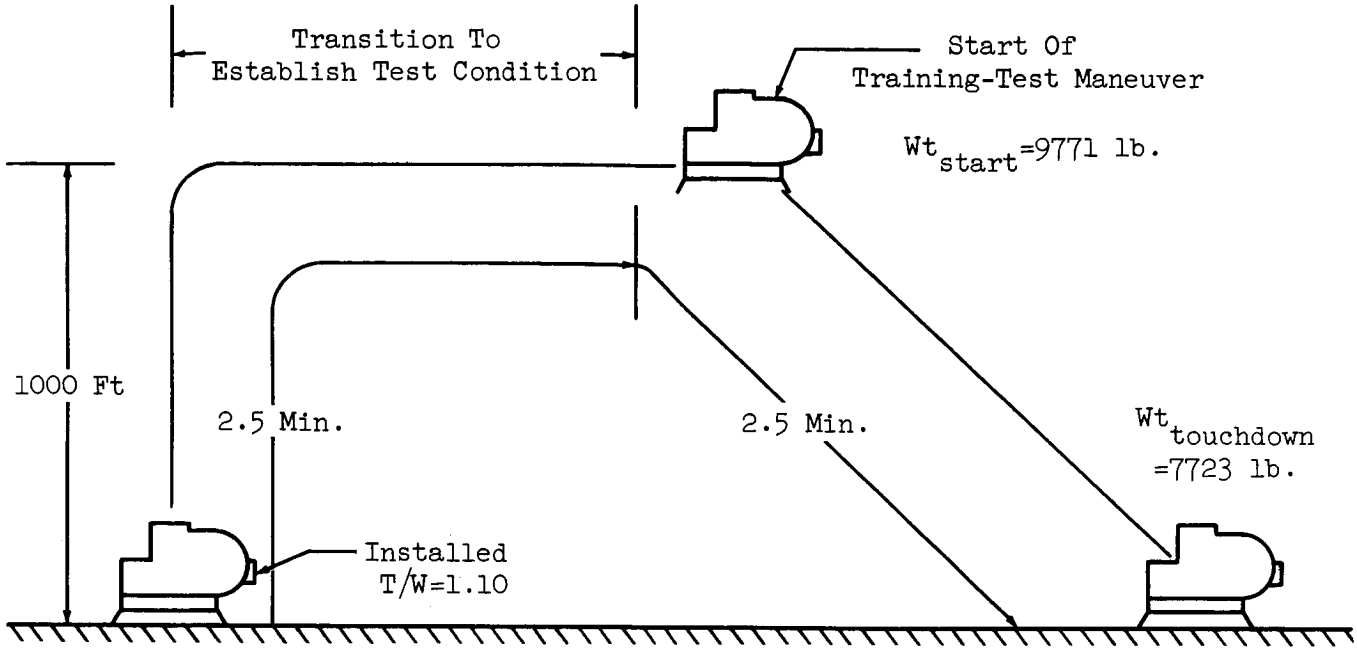
Recoil will be minimized by firing two chutes horizontally in opposite directions.

Impact energy dissipation can be further reduced through the utilization of pneumatic impact bags or crushable structure. The weight allocation for parachute and/or impact bag provisions is better deferred to the preliminary design phase rather than the feasibility study conceptual design stage. In the preliminary design phase, payload and c.g.-ballast requirements can be optimized and specific recovery system weights and volumes defined. As indicated by figure 8.5.

* Stencel recovery system weight for LTA-9 type vehicle is on the order of 380 pounds.
* Minimum practical sink rate is about 30 fps.

* Reference-1

Stencel, F.B., Stencel Aero Engineering Corporation, "Extending Capabilities of Escape and Aerial Delivery Systems", Aerospace Engineering, Vol. 18, No. 1 PP 47-52, January 1959.



Study Assumptions

1. Mil Thrust Levitation Engines
2. T/W=1.10 @ WSMR Ground Level
3. Installed Thrust Includes Losses & Bleed Air
4. Standard WARM Atmosphere
5. Test Site Altitude = 4000 Ft
6. LTA-9 Returned To Base By Auxiliary Means

Fig. 8.1 LTA-9 Mission Profile

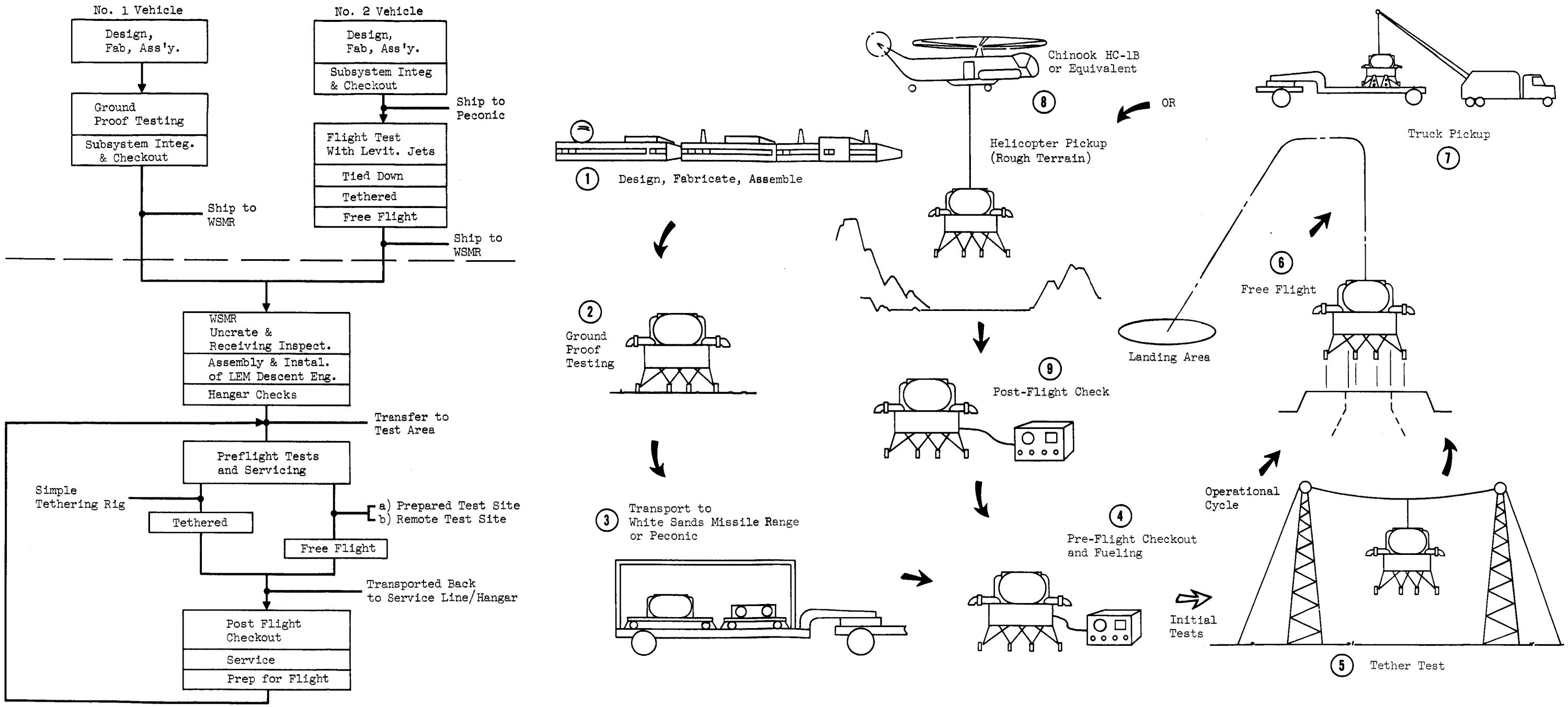
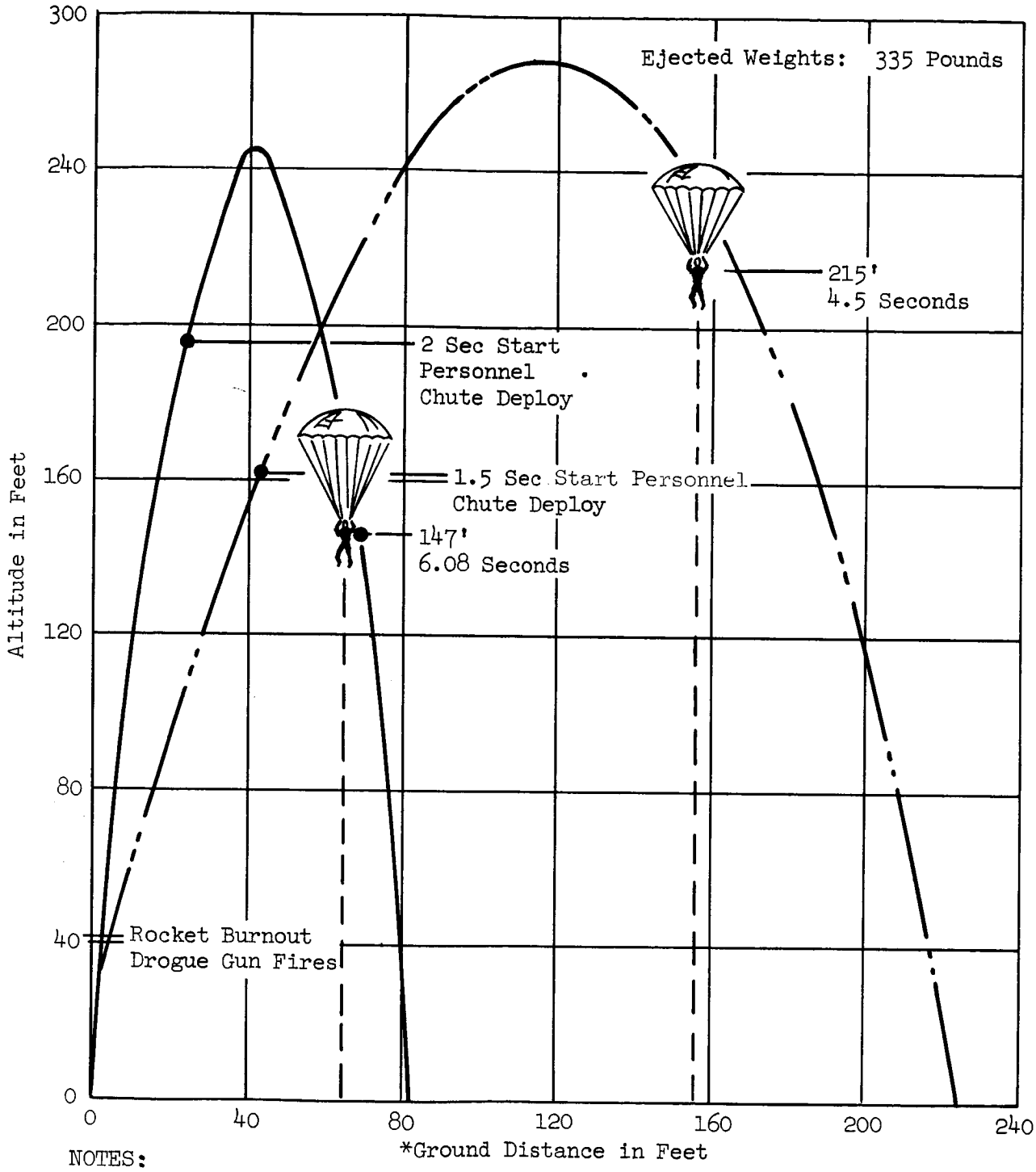


Fig. 8.2 LTA-9 Flow Diagram



NOTES:

——— Trajectory of #13 Test Ejection at Peconic River Facility

– – – – Estimated Trajectory under Optimized Conditions

— — — — Path of Man & Parachute After Separation from Seat when Terminal Descent Rate is Achieved, (No Wind)

*Ground Distance can be varied from zero to 450 ft. with system sink rate capabilities varying inversely with ground distance.

Fig. 8.3 Escape Trajectories for Zero Altitude, Zero Velocity Ejections

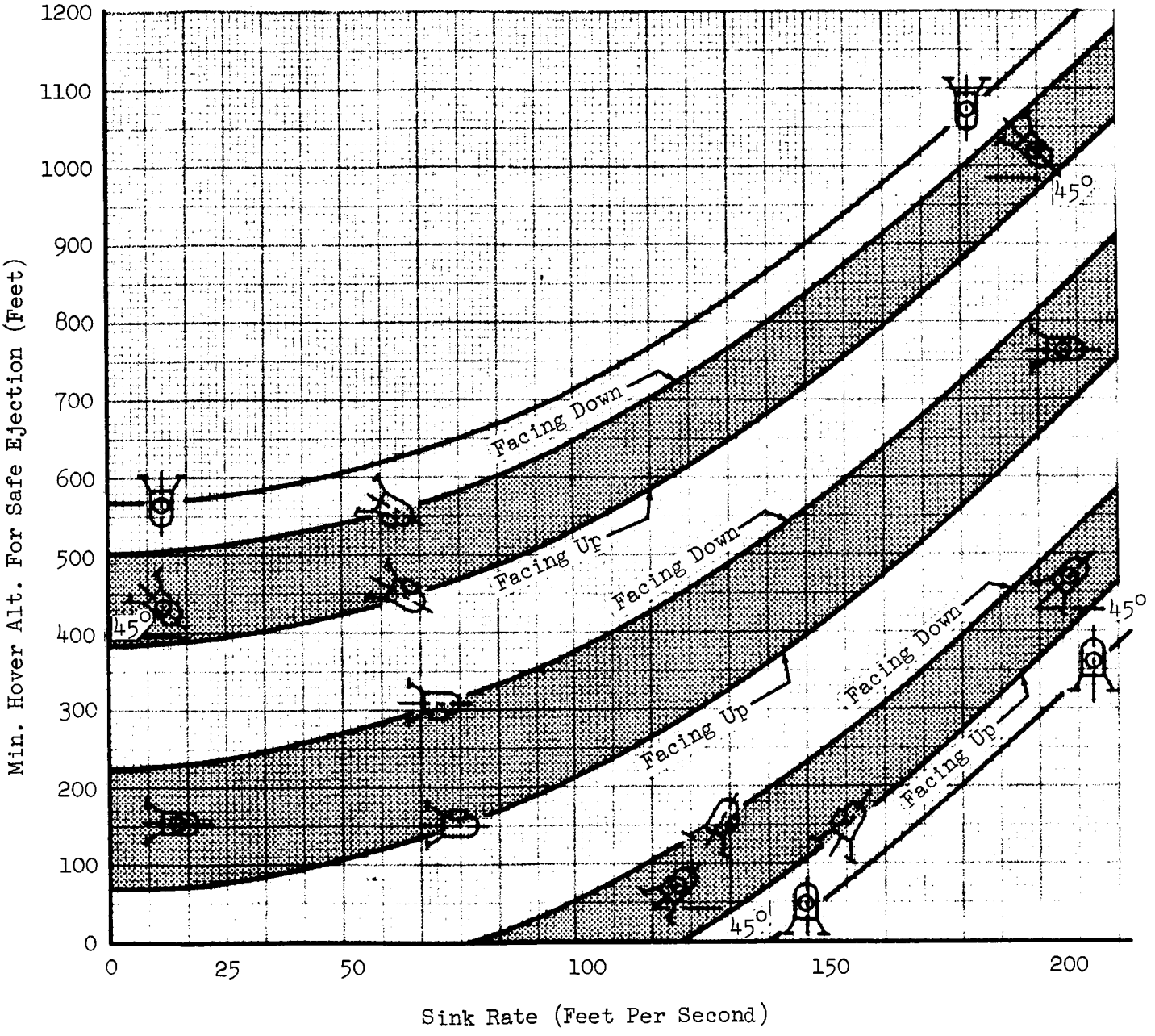


Fig. 8.4 Rocket Ejection Seat Escape Capabilities
Sink Rate vs. Minimum Safe Ejection Altitude
For Various LTA-9 Attitudes

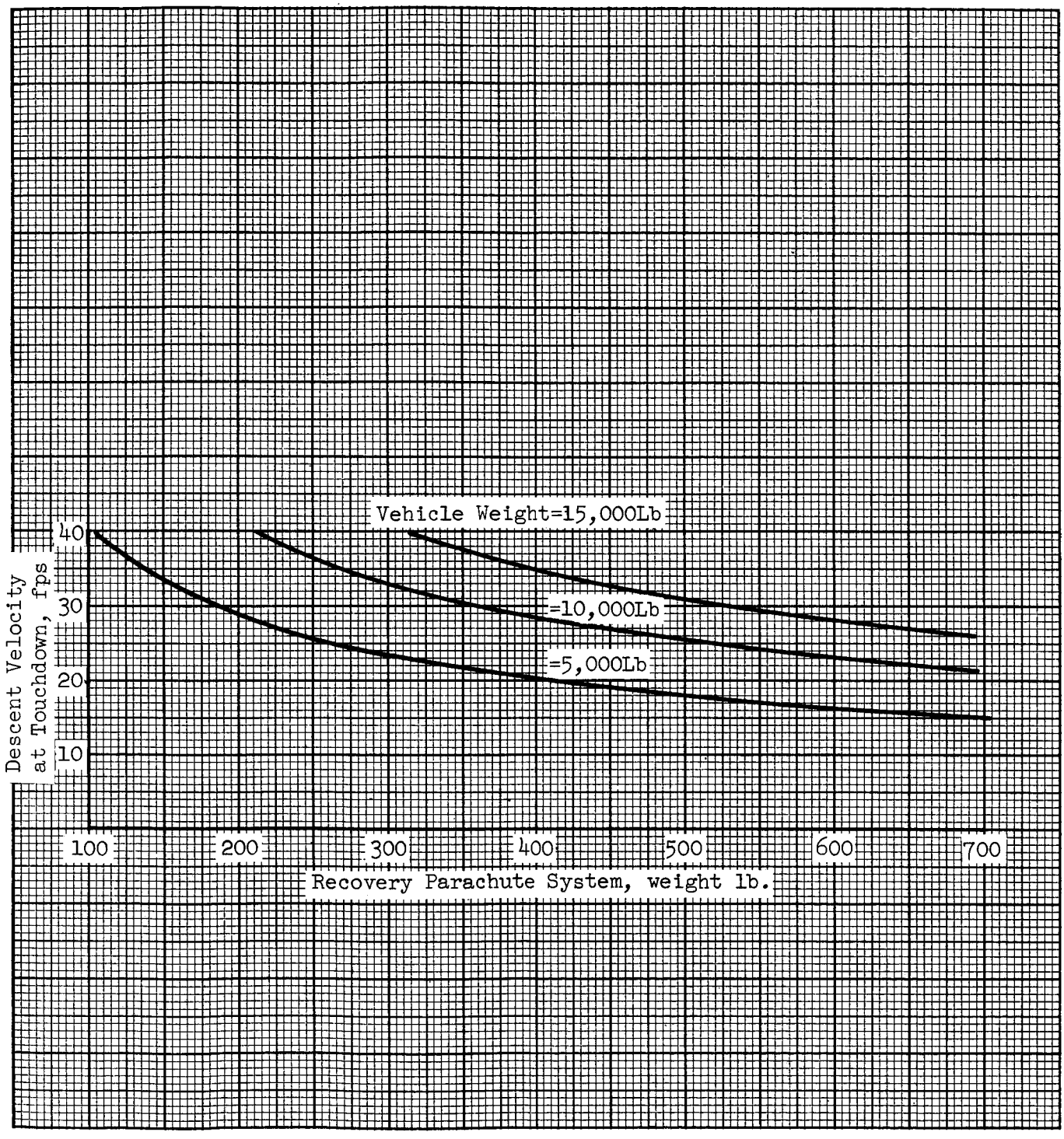


Fig. 8.5 Stencel Parachute Recovery System
(Estimated Minimum Recovery Height 100-150 Ft. - Zero Air Speed)

9. TASK CAPABILITY

9.1 INTRODUCTION

The value of a training or test system for the LEM terminal descent phase is proportional to its contribution to increase in success probability of the manned lunar mission. The lunar terminal descent presents demands for precise crew and vehicle response which are comparable with any other LEM maneuvering sequences. However, as shown in table 9.1, all other sequences, which include transposition, separations, staging, acquisition maneuver, rendezvous, and docking will be performed or practiced a number of times in space flight conditions prior to the manned lunar landing flight. Similarly, an LTA could be used to provide terminal descent handling experience and functional or evaluation testing.

However, the question of utilizing an LTA demands explicit consideration of the objectives and priority order of specific training and testing tasks. In this respect, the vehicle must be considered and integrated with the LEM Ground Test Plan, Simulator and Training programs, and the Flight Test Plan.

9.2 THE PRIMARY OBJECTIVES

The primary objectives of LTA-8 and LTA-9 vehicles are, therefore:

1. Increase the crew's proficiency in the terminal descent beyond that provided by ground based simulation.

2. Evaluation testing, to upgrade and refine the LEM and its subsystems for the terminal descent phase of the lunar landing mission, and supplement LEM space flight testing.

The LTA vehicles must provide a level of training and LEM handling experience exceeding that of any other vehicle in an environment that provides realistic crew working conditions, a high degree of mission realism, and a representative cross-section of terminal descent profiles. Upgrading of the LEM and the LEM sybsystems based upon atmospheric flight simulation of the terminal descent must also be achieved.

9.3 EVALUATION OF TERMINAL DESCENT AND LANDING TECHNIQUES

A free flying LEM supported solely by thrust places the astronauts in an environment in which flight safety is dependent upon the LEM and upon the crew's capabilities, The astronauts are divorced from the inherent security of ground based simulators and conventional lift supported aircraft. However, atmospheric free flight cannot implant the element of remoteness of an actual lunar landing 239,000 miles from earth and the thermal-vacuum conditions of space.

It is feasible to design a LEM LTA-9 configuration for hover, descent and landing which could eliminate aerodynamic effects and simulate the lunar gravitational field affecting LEM motions. The significant visual requirements for earth simulated terminal descent tests can also be met. The difference in earth and moon horizon depression angles (at a nominal 1000 ft. altitude) is not perceptible, i.e. on the order of 2 degrees. While there is uncertainty regarding lunar lighting a tolerable lighting simulation can be provided at WSMR by scheduling LTA-9 flight operations between twilight

Table 9.1

Preliminary LEM Flight Task Analysis

Lunar Landing Mission →	Lunar Ldg. Concept Demo.	Lunar Orbit Concept Check	Translunar Concept Simul.	Earth Orbit Systems Demo.	Earth Orbit Systems Check	Unmanned Earth Orbit Prop.	Unmanned Sub-Prop.Dev.
Functional Sequence ↓ / LEM No.→	10	9	8	6	5	3	1
Separate LEM from SM	X	X	X	X	X		
Transposition and Dock	X	X	X	X	X		
Pressurize LEM	X	X	X	X	X		
Transfer No. 1 Crewman	X	X	X	X	X		
All Systems Checkout	X	X	X	X	X		
Transfer No. 2 Crewman	X	X	X	X	X		
Recheck Systems	X	X	X	X	X		
Separate LEM & Perform all Systems Operational Checkout	X	X	X	X	X		
Inject into 50,000-ft Orbit	X	XX					
Checkout During Coast	X	Simul.					
Constant Burn Desc. to 1000'	X	Simul.					
Hover	X	Simul.					
Touchdown	X	Simul.					
Systems Checkout	X						
Explore & Rest	X						
Prelaunch Systems Checkout	X	Simul.					
Launch	X	Simul.					
Inject to Hohmann Orbit	X						
Coast	X	Simul.					
Terminal Rendezvous	X	XX	XXX				
Dock	X	X	XXX	X	XX		
Transfer Crew	X	X	X	X	X		
Separate LEM	X	X	X	X	X		
Abort During Descent		X					
			Navigation & Guidance & Propulsion System Tests	Propulsion & RCS Operation	Propulsion & RCS Tests	Propulsion and RCS Tests	Propulsion and RCS Tests

and dawn.*

Flight evaluation of terminal descent and landing techniques will be initiated from either a hover or some relatively low velocity, on the order of 75 fps. A representative cross-section of LEM descent profiles to be practiced include: the planned or nominal terminal trajectory, off-nominal trajectories and degraded mission trajectories. These profiles cover altitudes, ranges, sink and translational velocities of the entire terminal descent from initiation of LEM flight maneuvering at hover altitude through completion of touchdown dynamics. Table 9.2 summarizes the design capabilities of the conceptual LTA-9 vehicle. Typical terminal descent trajectories and flight characteristics are detailed in section 5.5.

Exposure to the operations discussed above should increase the crew's confidence in the handling characteristics of the LEM. At the same time, experience in LTA-9 should raise the confidence level of each crew member's ability to control the LEM in terminal descent. Finally, this training should confirm crew member responsibilities and task sharing in the landing phase of the LEM mission under a flight operational environment.

*

It has been experimentally determined that from the moon, a full earth appears as a minus 17 magnitude star, producing a mean value of flux density at the moon's surface of 1.412 foot-candles. The average albedo (reflectance) of the moon is 0.07, so that reflected earthshine or luminance is 0.099 ft.-lamberts or approximately 0.1 foot-lamberts. In order to simulate these values of illumination for the tests at White Sands Missile Range the operation must be made just before sunrise or after sunset. The light values are changing so rapidly at this time, however, that only one or two minutes will be available to complete the operation.
Light levels could be controlled by means of variable neutral density window or face plate inserts which filter out light without distorting color. Average reflectance light values of the area should be measured by means of a photometer at about the time of day that the test flight is desired to be made. The transmittance of the filters should then be adjusted to produce the desired 0.1 ft.-lambert value in the cockpit.

Table 9.2

LTA-9 Atmospheric Free Flight Vehicle

Design Criteria	
Crew	2
Displays for Terminal Descent	LEM
Overall Cockpit Arrangement	LEM
Escape System	Rocket Seat Ejection
Flight Time (Max)	5 Minutes
Take-off Gross Weight	10168 lbs. (earth)
Start of Descent Gross Weight	9685 lbs.
LEM Descent Engine Propellant Weight	1674 lbs.
LEM Descent Engine Thrust (Max)	7100 lbs.
LEM Descent Engine Throttling Ratio (Max)	6.75
Descent Engine Operating Time (Max) Per Mission	150 sec.
Levitation Engine System	Six S J-132 Engines
Installed Thrust Available (4000'H_p, 75°F.)	13150
T/W (WSMR T. O. Terrain alt. 4000')	1.10 +
Maximum Altitude	8000' H_p
Maximum Speed ("Severe Trajectory)	75 Fps.
LTA-9 Time Constants in Automatic EEC Mode	
Pitch	0.400sec@hover to0.339@touchdown
Yaw	0.400sec@hover to0.368@touchdown
Roll	0.400sec@hover to0.354@touchdown
LTA-9 Maximum Angular Parameters:	
Pitch: Angle; Rate; Acceleration	$\pm 30^{\circ}$; 38.7°/sec; 49.9°/sec^2
Yaw: Angle; Rate; Acceleration	$\pm 15^{\circ}$; 23.6°/sec; 38.4°/sec^2
Roll: Angle	$\pm 360^{\circ}$
Landing Velocities	
Horizontal	5 fps
Vertical	10 fps

LEM terminal descent and landing practice afforded by the LTA-9 vehicle is summarized in task form in table 9.3. Throughout these free flight operations, planned malfunctions could be introduced to test the crew's ability to recognize errors and potential hazards and practice correcting actions. In the landing dynamics area combinations of surface conditions and grades can be introduced to better familiarize the astronaut with LEM touchdown characteristics.

Table 9.3

LEM Terminal Descent and Landing Experience Gained in LTA-9
LEM Descent Engine Thrusting and Thrust Vectoring in Free Flight Including Hovering
LEM Descent Engine Propellant Management
LEM Response to Reaction Controls
Three Dimensional Flight Path Maneuvering and Ranging Technique Development in Free Flight
Practice with and Investigation of Landing Aids
Landing and Touchdown Dynamics on Various Grade-Surface Combinations
Decision-Action Practice in Flight Along the Trajectory
LEM Repositioning to Prepare for Abort in Terminal Descent Phase

9.4. LEM UPGRADING AND REFINEMENT

9.4.1 Timeliness

Along with acquiring LEM handling experience LTA-9 provides an opportunity to upgrade and refine the LEM and its subsystems.

LTA-9 is the only LEM type vehicle that will be exposed to a flight environment and return to earth intact. Considering the fact that the environment is atmospheric flight as opposed to space flight, the value of LTA-9 tests are primarily for systems upgrading and for reliability data on LEM subsystems. Timeliness of inputs to the LEM program is an important consideration in this area. The potential for LEM subsystem feedback to the basic LEM Development Program starts in mid-1965 when the LTA-9 enters flight test, 18 months prior to operational LTA-9 usage.

9.4.2 LEM Subsystem Refinement

LEM subsystems, which will be refined through terminal descent operational tests, include radar(with a preliminary evaluation of electromagnetic interaction between radar signals and ionized rocket engine discharge), inertial platform elements, reaction control hardware, cockpit displays, lighting and equipment locations, crew mobility and restraints. These flight operations and the LEM descent engine operations are also a source

of further confirmation of the LEM's structural integrity under dynamic and transient loadings. Additional LEM components will be carried on a "ride along" basis rather than on an "essential to terminal descent" basis.

This upgrading and refinement of LEM hardware with regard to performance, accuracy, stability and reliability will be conducted under as near lunar terminal descent conditions as possible. The results of these atmospheric flight operations in conjunction with the space flight environment testing afforded by LEM No. 9 (refer to table 9.1) should assist in confirmation of LEM hardware and operations. Table 9.4 summarizes the areas in which the LTA-9 can provide upgrading and refinement LEM equipment.

Table 9.4

LEM Upgrading And Refinement Provided By LTA-9
LEM Response and Sensitivity to Thrust and Reaction Control
Comparison of Manual and Automatic Modes with Regard to Hardware Operation
Radar Altimeter Performance (incl. limited evaluation of rocket ionization effects)
RFI Effects on Flight Control Elements and Communication In Flight
Cockpit Layout and Lighting in Terminal Descent
Crewman mobility and Restraints
LEM Equipment Not Essential to Terminal Descent Phase But Carried on a "Ride-Along" Basis
Structural Upgrading of LEM Equipment Based on Flight Experience

9.5 PRELIMINARY EVALUATION OF CAPABILITY WITH RESPECT TO ALTERNATE METHODS

9.5.1 Training Requirements

In evaluating the capability of LTA-9 as a vehicle for proof-training in the hover-to-touchdown phase of the LEM lunar landing mission a general review of the projected requirements and a rating of the capacity of various vehicles and devices for satisfying these training requirements is in order. Table 9.3 summarizes this review. No attempt has been made to compare or rank the requirements on the basis of criticalness to the mission. The tabularized ratings achieved by the various vehicles for this mission phase are not intended to indicate per se the best method of achieving the requirements.

A complete evaluation should include: test requirements, scheduling, development, safety, overall utility and the capacity of a device for rapid recycling. Allied considerations such as, flexibility in scheduling of the use-time, minimum down time and reliability must be investigated.

The requirements for, and ease of inclusion of techniques and instrumentation for monitoring and evaluation of crew performances must also be taken into consideration. Thus, the net rating which any vehicle might achieve when all these factors are included might be quite different from the sum of the ratings indicated in table 9.5. Final evaluation will be submitted subsequent to this report after completion of concurrent study on alternate flight training vehicles.

NOTE:

The final evaluation is dependent upon the results of a concurrent study on alternate flight training vehicles and will be submitted, subsequently.

The descriptive adjectives utilized in table 9.5 refer to the capability of the device for satisfying the training requirements of the LEM Lunar Landing Mission. Devices were rated as follows:

Good - If the training requirement can be adequately satisfied

Fair - If the training requirement can be adequately satisfied but only through introduction or acceptance of factors extraneous to the requirement or mission.

Limited- If the training requirement is inadequately satisfied and the utilization of the device may involve extraneous factors.

Poor - Regardless of the capability of the device to satisfy the requirement, the utilization of device will probably involve aspects of negative transfer which could be critical LEM operation.

Not Applicable-Training requirement cannot be satisfied.

The following assumptions are made regarding the vehicles rated in table 9.5 :

Part Task Trainers - These trainers will be designed and developed to yield a high degree of simulation fidelity for performance of the particular task involved. Obviously a number of trainers may be required to meet the total training requirements of the landing phase.

Mission Trainer - This trainer will be designed and developed to yield a high degree of simulation fidelity encompassing all aspects of the mission. It will be a complete and accurate simulation of all LEM subsystems and subsystems operation, with the probable exclusion of vehicle motion.

Tethered Rig*(Langley: Fitted with LEM vehicle) - This device is the Langley Research Center's tethering rig fitted with a LEM vehicle. The LEM will be modified as required by the weight limitation (capacity) of the rig. This LEM's maneuvers would be precise within the restriction of the travel and acceleration limits of the rig.

VTOL Aircraft - Ratings for this type of vehicle are based on current configurations with little modification anticipated. Resemblances to LEM maneuver and vehicle response characteristics are expected to be gross.

Bell Free-Flight Vehicle - Ratings for this vehicle are based on the currently anticipated design configuration and payload as a research vehicle and do not encompass possible design modification to LEM configuration.

LTA-9 - A vehicle expressly designed and developed to simulate with highest fidelity possible the response characteristics of the LEM vehicle in the lunar environment.

* It should be noted that operating the LEM with hypergolic propulsion and RCS places higher handling safety demands on the tether facility test personnel than the hydrogen peroxide systems currently planned for the Langley Lunar Landing Research Facility.

TABLE 9.5

LEM TRAINING REQUIREMENT *	Part Task Trainers	Mission Trainer	Tethered Rig (Langley with LEM) (fitted)	VTOL Aircraft	Bell Free-Flight Vehicle	LTA-9 Type Vehicle
Practice control of thrust to maintain hover.						
(gross)	Good	Good	Good	Fair	Good	Good
(fine)	Good	Good	Fair	N.A.	Fair	Good
Practice in manual control of attitude at hover.						
Primary Mode						
(Gross)	Good	Good	Fair	Poor to Limited	Good	Good
(fine)	Good	Good	Fair	N.A.	Fair	Good
Back-Up Mode						
(Gross)	Good	Good	Good to Fair		Good	Good
(fine)	Good	Good	Fair		Fair	Good
Provide appropriate external visual cues for: (2)						
Attitude Judgement	Good	Good	Fair to Limited	Fair to Good	Fair to Good	Fair to Good
Inference of Motion						
(translation)	Good	Good	Fair to Limited	Fair	Fair to Good	Fair to Good
(rotational)	Good	Good	Fair to Limited	Fair	Fair to Good	Fair to Good
Altitude & Range Judgements	Good	Good	Limited	Fair	Fair	Fair
Provide practice in utilization of visual cues for initiation of appropriate action. (3) (4)	Fair to Good	Good	Limited	Poor	Fair to Limited	Good
Provide appropriate change in visual cues relative to pilot's vehicle control. (3) (4)	Good	Good	Limited	Fair to Limited	Fair	Fair to Good
Provide physiological cues of motion if required or appropriate. (1)	Fair to Good	N.A.	Fair	Good to Fair	Good or Poor (May yield inappropriate cues)	Good or Poor (May yield inappropriate cues)
Practice in thrust management during various descent profiles (e.g. vertical descent nominal descent flare type descent	Limited to Fair	Good to Fair	Limited	Poor to Limited	Limited	Good to Fair
Practice of roll maneuver to survey terrain or acquire line-of-sight.	Good	Good	Fair to Limited	Poor (involves use of different control configuration for LEM)	Fair	Good
Practice pitch or yaw maneuver through RCS control for translation.	Good	Good	Limited	Poor	Fair	Good

* Numbers shown after requirements statement refer to "remarks" column.

REMARKS

1. It has been commented upon by Mercury flight astronauts that rotational motion in space more nearly resembles a motionless state then a rotating motion in a 1 "g" environment insofar as body sensations are involved. Thus, it is possible that the physiological sensations experienced in training with earth free flight vehicles or moving simulators would be utilized as motion cues, whereas such cues would not exist (or exist to a much lesser degree) in the lunar environment).
2. The ratings for this requirement are primarily a function not of the vehicles involved, but rather of the extent to which visual light levels expected in the lunar environment can be accurately reproduced. Motion is inferred more readily when terrain can be easily seen and differentiated from sky. As terrain and/or sky become more homogeneous (low light levels) these motion cues are degraded. The same is true of judgements of altitudes which are to a great extent dependent on the size constancy perceptual cue whose utility is also degraded when light levels are low or terrain features relatively unfamiliar. It is felt that the level of external visual cues might be more accurately presented in controlled (simulation) rather than ambient (earth) light conditions.
3. The full range of visual cues (which result from vehicle attitudes and rates) cannot, (tethered rig), or for reasons of safety should not (Bell, VTOL vehicle) be allowed to occur thus limiting the range of practice with these vehicles in utilizing visual cues.

TABLE 9.5 (Contd.)

LEM TRAINING REQUIREMENT	Part Task Trainers	Mission Trainer	Tethered Rig	VTOL Aircraft	Bell Free-Flight Vehicle	LTA-9 Type	Remarks
Practice RCS control to effect translation (without vehicle altitude change) if required.	Good	Good	Limited	N.A.	Fair	Good	4. Visual cues resulting from high vehicle rotation or translation rates are not capable of presentation on tethered rigs.
Practice in manual control of attitude during various descent profiles.							
Primary Mode (Gross)	Good	Good	Fair	Limited	Fair to Limited	Good	
Primary Mode (Fine)	Good	Good	Limited	Poor	Fair to Limited	Good	
Back-Up Mode (Gross)	Good	Good	Fair	Limited	Fair to Limited	Good	
Back-Up Mode (Fine)	Good	Good	Limited	Poor	Fair to Limited	Good	
Practice in interpreting and utilizing info from applicable flight instrumentation displays.	Good	Good	Fair	N.A.	Fair to Limited	Good	
Practice in monitoring LEM subsystem status during landing maneuvers (provision for time sharing activity).	Good	Good	Fair to Limited	N.A.	Limited	Good to Fair	
Practice with various control modes in acquiring the terminal vehicle conditions required for touchdown.	Good	Good	Fair to Limited	Limited	Fair	Good to Fair	
Provide appropriate physiological cues of lunar touchdown (drop, surface contact results of torque rates) if desired for realism only.	N.A.	N.A.	Fair to Good	Limited to Poor	Fair to Limited	Fair to Limited	
Provide capability for inserting of subsystem malfunctions requiring crew decisions and corrective action.	Limited	Good	Fair	N.A.	Limited or N.A.	Fair to Limited	
Provide practice in making and implementing abort decisions, based on inserted malfunctions or gross pilot mal-performance.	Fair	Good	N.A.	N.A.	Limited	Limited	
Make provision for time shared practice of associated tasks not directly related to flight control or subsystem status. e.g. 1. Deployment of landing aids. 2. Determination of landing site suitability. a. Surface hardness b. Terrain slope 3. Communications Tasks	Limited or N.A.	Good to Fair	N.A.	Limited or N.A.	Limited or N.A.	Fair to Limited	